30

TERTIARY STRATIGRAPHY OF THE MORNINGTON DISTRICT, VICTORIA

By V. A. Gostin

Department of Geology, University of Melbourne

Abstract

The Tertiary sequence of the Mornington Peninsula is best exposed in the coastal region between Frankston and Mt Martha, referred to as the Mornington District. The detailed stratigraphy, sedimentology, and structure of the Tertiary strata of this area are described.

Sedimentation during the Tertiary began with the deposition of fluviatile sediments including coarse gravels, sands, and finer carbonaceous silts. A period of basic volcanic activity intervened during the Oligocene.

During the Miocene a marine transgression began with the deposition of littoral and near-shore sands. These form the Mt Martha Sand Beds in the south whereas, at Manyung Rocks to the north, a much thinner sand layer is succeeded by deeper water silts of Batesfordian age. Fluviatile conditions recurred in the south and the thin Harmon Rocks Sand Bed was deposited.

The early marine phase was followed during the Balcombian, by widespread deposition of marine calcareous clayey silts forming the Balcombe Clay. The maximum trangression during the Balcombian and Bairnsdalian was followed by gradual withdrawal of the sea. Shallow marine conditions were present towards the end of the Bairnsdalian when the fine Marina Cove Sand was deposited. The regression was completed during the late Tertiary with a change to fluviatile conditions and the deposition of the Baxter Sandstones.

Much of the faulting in the Mornington District occurred during the late Tertiary and was accompanied or followed by a period of intense leaching and ferruginization which affected all the near-surface beds.

Introduction

Regional Geology of the Mornington Peninsula

The bedrock of the Mornington Peninsula consists of steeply folded Ordovician and Silurian sediments, intruded by granitic plutons of probable Upper Devonian age (Fig. 1). A small fault remnant of non-marine Mesozoic sediments occurs near Mornington.

The Palaeozoic rocks may be regarded as forming the central axis of the Peninsula, flanked on either side by a variable thickness of Tertiary sediments and volcanics. Lower Tertiary basalts cover much of the southern part of Mornington Peninsula, whereas undifferentiated ferruginous sands and clays form the surface of the central and northern parts. Exposures of other Tertiary sediments are restricted to the Mornington District in the north-west, and to a small limestone outcrop at Flinders in the south. In other areas the Tertiary sequence can be studied only in bores, as at Tyabb in the north-east, or underlying thick Quaternary sediments of the Nepean Peninsula.

Tectonic Setting

During the Tertiary, tectonic activity on Mornington Peninsula was restricted to normal faults with associated flexures and broad folds. Several faults have shown recurrent movement and probably date back to the Palaeozoic. The strike of the major faults is parallel to the trend of the folded Palaeozoic sediments although several cross faults and diagonal faults are known (Keble 1950, p. 34).

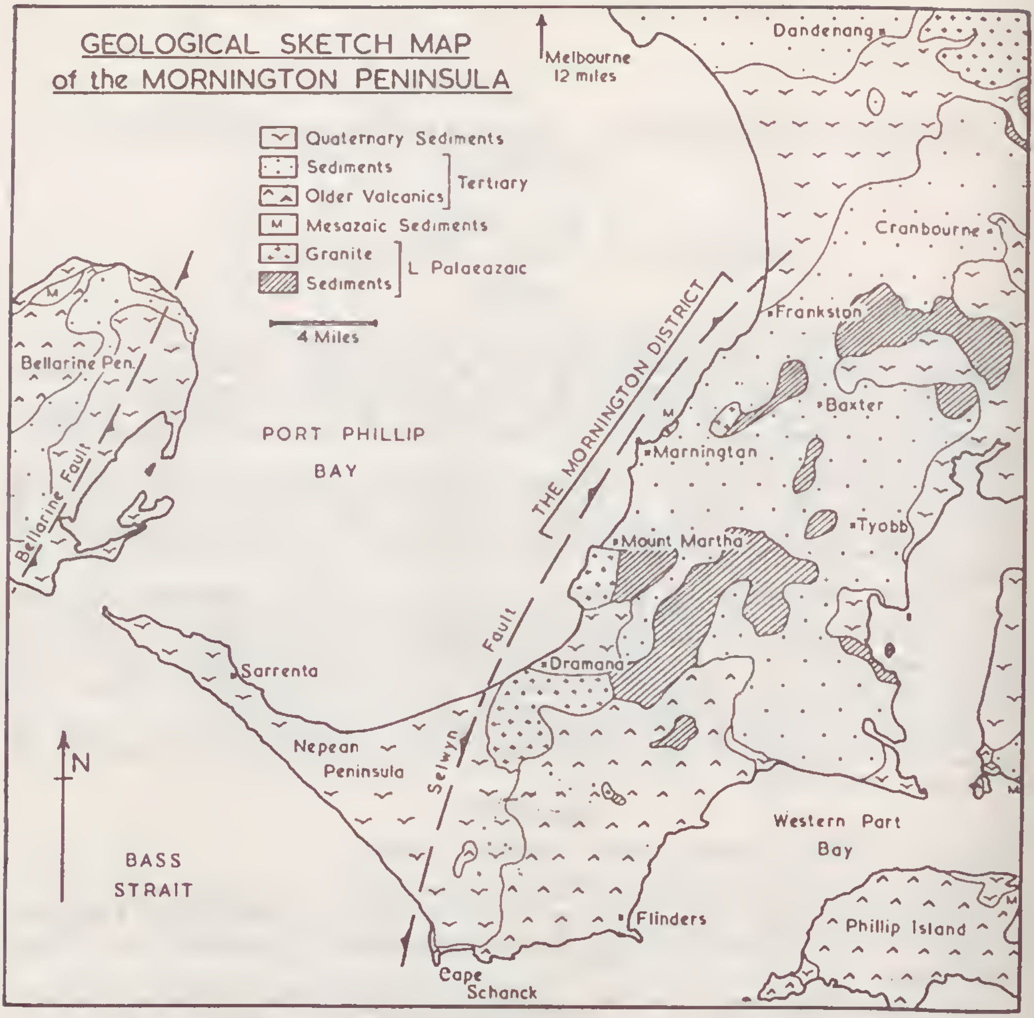

FIG. 1—Locality Map.

Selwyn Fault is by far the most important of the Tertiary structures. It forms the western edge of the Peninsula and has downfaulted Tertiary sediments in the Nepean Peninsula and Port Phillip Bay to the west. The faults on the eastern side of Mornington Peninsula are comparatively small, and the Tertiary sediments of Western Port Bay are downthrown to the east. The Mornington Peninsula is thus a relatively uplifted block with a prominent graben to the west (the Port Phillip Sunkland), and a lesser negative area to the east (the Western Port Sunkland). The Tertiary sequence of the Mornington District has been deposited on the upthrown side of Selwyn Fault, and is thus relatively thin when compared with equivalent sediments in the bores of the Nepean Peninsula. These bores indicate the throw to have been over 2,000 ft during the Cainozoic.

GRAVITY DATA: Gravity observations of Port Phillip Bay and the Mornington

Peninsula clearly show the Selwyn Fault structure to be of primary importance in the area (Gunson, Williams, & Dooley 1959).

Off the coast of Mt Martha and Dromana, the gravity contrast is about 10 milligals over a distance of a mile, and assuming a maximum density contrast of 0·6 gm/cc, the minimum displacement would be about 1,300 ft. Seeing that the total contrast in the area is some 40 milligals, the actual throw on Selwyn Fault is very much greater.

The negative anomaly in the southern part of Port Phillip Bay may partly result from downfaulted Mesozoic sediments, a small remnant of which may be seen near Mornington. An E.-W. gravity trend line offshore from the northern coast of Bellarine Peninsula to Mornington suggests the northern limit of these sediments in Port Phillip Bay, and is supported by the available geological information on the western and northern coasts of the Bay.

Off the Frankston coast the gravity contrast is some 20 milligals, and because no Mesozoic sediments are expected to be involved, the displacement of Cainozoic strata is still considered to be greater than 2,000 ft.

Previous Literature

Before the present century the Tertiary sediments of the Mornington District were briefly referred to by Selwyn, McCoy, and Tate & Dennant. Kitson in 1900, and Hall & Pritchard in 1901, described the regional geology of the area and provided sketch maps along with a few illustrated sections. The latter authors also gave a comprehensive faunal list from the well known locality at Fossil Beach (Mornington), and from other outcrops of the Balcombe Clay.

Except for a couple of papers by Chapman and Keble, most of the later reports were concerned with descriptions of fossils, and made only passing reference to the stratigraphy. A full bibliography of this literature was published by Singleton (1941), who also clarified certain problems relating to the stratigraphy and structure of the Balcombe Clay, and gave a correlation with other Victorian Tertiary sequences.

Keble in the Memoir on the Mornington Peninsula (1950) reviewed the existing literature, assembled the stratigraphic data, and gave several original cross sections. It can be remarked, however, that no detailed stratigraphic correlation or study of the petrology of the Tertiary sediments has been made in the Mornington District. References to specific publications are further made in the relevant parts of the text.

Method of Study and Presentation of Results

In the following text, 23 Sections and Localities representative of the Tertiary sequence in the area, are described in order proceding from Frankston, S. to Mt Martha. Their positions are shown on Fig. 4. Unless otherwise specified, sections are based on mean low-tide level. Reference to a particular bed within a section is simplified by combining the section number with the appropriate letter of the bed: e.g. bed (g) of Section 10A is referred to as bed 10A(g). Nearly all the lithological descriptions were made during field work, but where laboratory study showed inaccuracy, the descriptions were modified.

The term 'calcareous' is used to denote the presence of carbonate, mainly in the form of calcite. Similarly 'non-calcareous' means the absence of carbonate, and not necessarily the absence of calcium. The term 'ferruginous' signifies the intense colouration resulting from the presence of iron oxides. On exposure this is usually accompanied by varying degrees of cementation. The term 'cemented' is used to emphasize such lithification.

Grain size analysis of the sand components of a sediment was carried out by dry sieving, and an adaptation of the hydrometer method was used for silts and clays. Results were plotted on cumulative log-probability paper and for samples that were not strongly bimodal, statistical parameters of Inman (1952), and the mean size and standard deviation of Folk & Ward (1957) were determined. The ϕ grain size notation (Krumbein 1934) has been used throughout, and the descriptive sorting classification is that of Friedman (1962). After sieving, the general mineralogy and roundness of the sands were determined using a binocular microscope, the roundness scale being that of Powers (1953). Further details of the analytical methods employed may be seen in Gostin (1964).

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Geology of the Mornington District with Descriptions of Measured Sections

The coast from Frankston to Mt Martha provides almost all the significant Tertiary exposures in the Mornington District. Dennant and Grices Creeks are the only inland localities that reveal a Tertiary sequence, and then only after heavy rains have cleared away the abundant debris. Along the coast, the generally weak nature of the sediments has resulted in severe landslips and abundant hillwash, so that well exposed sections are rare. The first locality is about ½ mile S. of the Frankston Jetty, before the rise up Olivers Hill, where a small projecting cliff shows a sedimentary sequence dipping at 10°-20° northward.

SECTION 1: BASE OF OLIVERS HILL

Bed	Thickness	Description
(f)	7′ +	Strongly weathered and partly ferruginized basalt.
(e)	*c.* 5′	Fine to coarse sands. Upper part of bed obscured by detritus and probably landslipped.
(d)	*c.* 1′	Coarse clayey sands. Discontinuous and with gradational boundaries.
(c)	2′-3′	Medium clayey sands.
(b)	3′	Very coarse quartz grit, with little clay.
(a)	*c.* 8′	Cobble gravel or conglomerate, with pebbles, cobbles, and a few boulders of Palaeozoic rocks (largest measured: 15″ × 9″ × 7″). Interstices filled with sand and silt. Cobbles mainly of sandstone and quartzite, some dark graptolitic shale and spotted slate, rare reef quartz. Sandstone cobbles are faceted with rounded corners; shale pebbles are sub-rounded tabular. The bed is strongly weathered.
		The shore platform consists of fractured granite which rises up to 20′ above sea level. The granite is strongly weathered in the cliffs.

This section was first described and illustrated by Kitson (1900, p. 7). The granite at the base can be followed S. to Landslip Point where the following section was measured.

SECTION 2: LANDSLIP POINT

Bed	Thickness	Description
(i)	25′ +	Loose and slipped sequence of mottled, ferruginous silts, sands, and fine gravels.
(h)	2′ +	Olive-grey, structurally homogeneous clayey silt.
(g)	4″-9″	Irregular, ferruginous and partially cemented, red-brown horizon, with a fine texture, and containing moulds of Tertiary mollusca.
(f)	4″	Average thickness of olive-grey clayey silt with impressions of mollusca. Basal part consists of lenses of silt in a sandy matrix.
(e)	1′	Coarse, poorly sorted clayey sand.
(d)	6″-9″	Friable well sorted medium sand. Yellowish grey colour and with a few ferruginized worm burrows.
(c)	11′	Yellow to red, ferruginous coarse and fine grits. Steep cross-bedding. Cemented in irregular layers.
	5′	Covered interval.
(b)	10′	Coarse sand grit; arkosic, with felspars decomposed to clay.
(a)	3′	Discontinuous layer of cobble gravel, or conglomerate. Pebbles and cobbles of Palaeozoic sandstone, quartzite, and shale.
		Strongly fractured and weathered granite rising from sea level up to about 30′. At the base of the section and within the granite, are veins of siderite, partly or completely oxidized to limonite.

Basalt was not seen at this point but occurs a short distance to the south where the beds dip down to sea-level. Its stratigraphic position is some 20 ft below bed 2(g) according to Kitson (1900, Section C-D) and Hall & Pritchard (1901, p. 36). This latter bed, which is fossiliferous, can be traced for some 40 yds along the cliff face, beyond which it has been obscured by landslips.

Locality 3 is a very small projecting point about ¼ mile S. of the previous locality. The cliffs consist of fractured and partially weathered granite overlain by more than 8 ft of a cobble gravel or conglomerate, being the continuation of bed 2(a). The granite surface slopes down to the north from 30 to 15 ft above sea level, whereas the point itself consists of partially weathered basalt which is downfaulted against the granite. The fault zone is several feet wide and contains sheared and strongly weathered coarse sandy gravel. Both Kitson (1900, p. 7) and Hall & Pritchard (1901, p. 37) were puzzled by this outcrop, but did not regard it as resulting from a high-angle normal fault, with a strike almost parallel to the shore. Northward, the fault appears to pass inland from Landslip Point, whereas southward it lies a few yards off-shore and may be followed to the mouth of Naringalling Ck. On the S. side of this creek the fractured granite forms a cliff about 80 ft high. The shore platform consists of weathered and partly ferruginous basalt, which, a few yards to the south, overlies the granite high in the cliff. The junction here is sharp and no intervening gravel was seen. The average strike of the fault is thus about 40°T (true bearing), with downthrow to the NW. It follows that the coast S. of this point should reveal younger strata, seeing that it lies on the W. side of the fault. This is borne out by the presence of marine Tertiary sediments at Daveys Bay, probably equivalent to the marine beds 2(f)-(h) at Landslip Point.

The coast on the eastern side of Daveys Bay is severely landslipped and forms a low point, on the western side of which, at Locality 4, some grey clayey silt is exposed. This sediment is non-calcareous but contains faint impressions of Tertiary mollusca. It is stained yellow along the numerous joints. Stratigraphic relationship to the adjacent mottled and ferruginous sands and clays is confused by the landslip.

Some 200 yds S., at Locality 5, a cliff of relatively undisturbed sediment rises some 80 ft above sea level. The section, dipping gently to the south is as follows:

SECTION 5: DAVEYS BAY

Bed	Thickness	Description
(c)	50′ +	Mottled red and grey sands and clayey sands.
(b)	c. 5′-10′	Very fine, yellow and partly ferruginous sands.
(a)	20′	Light grey, olive and yellow mottled silts and clays. Indistinctly layered. Worm burrows and siliceous sponges present. (This bed forms a platform below sea level.)
	5′	Beach sand, covered interval.

At Davey Point, ferruginous, mottled, and partially cemented sands and clayey sands form cliffs about 30 ft high. Strongly cemented blocks of the same material, 'ironstones', cover all the shore platform. On the western side of the point, the following section was measured:

SECTION 6: DAVEY POINT

Bed	Thickness	Description
		Buckshot gravel at the surface.
(c)	15′ +	Ferruginous, mottled and partially cemented coarse sands, and finer clayey sands. Cross-bedded.
(b)	c. 10′	Yellow very fine sand, ferruginous and partially cemented. Lower half of bed poorly exposed.
(a)	1′ +	Olive yellow silt or fine clayey sand. Very poor exposure and possibly grading into bed (b).
	4′	Covered interval.

Comparison with Section 5 shows a general correspondence, and seeing that both sequences are almost flat-lying, a gentle undisturbed westerly to south-westerly dip must be present. The general structure of the beds from Sections 1 to 6 is summarized in Fig. 2. The top of bed 6(b) has a slight southerly dip, so that the next point to the south (Pelican Point) consists entirely of the overlying ferruginous, cemented, and generally coarse sands.

Between Pelican Point and Griees Ck, the coastal section consists entirely of ferruginous, poorly sorted coarse to fine, and clayey sands. The headlands are composed of well cemented sands (ironstones), whereas bays have developed in regions of less intense cementation (e.g. Canadian Bay). The sands usually show steep cross-bedding, with sets of cross-strata up to 1 ft thick. Dips measured on the major bedding planes are plotted on Fig. 4.

Inland from the coast, the surface of the land rises up to Mt Eliza (504′), and consists of undifferentiated ferruginous sands capped with buckshot gravel. Above

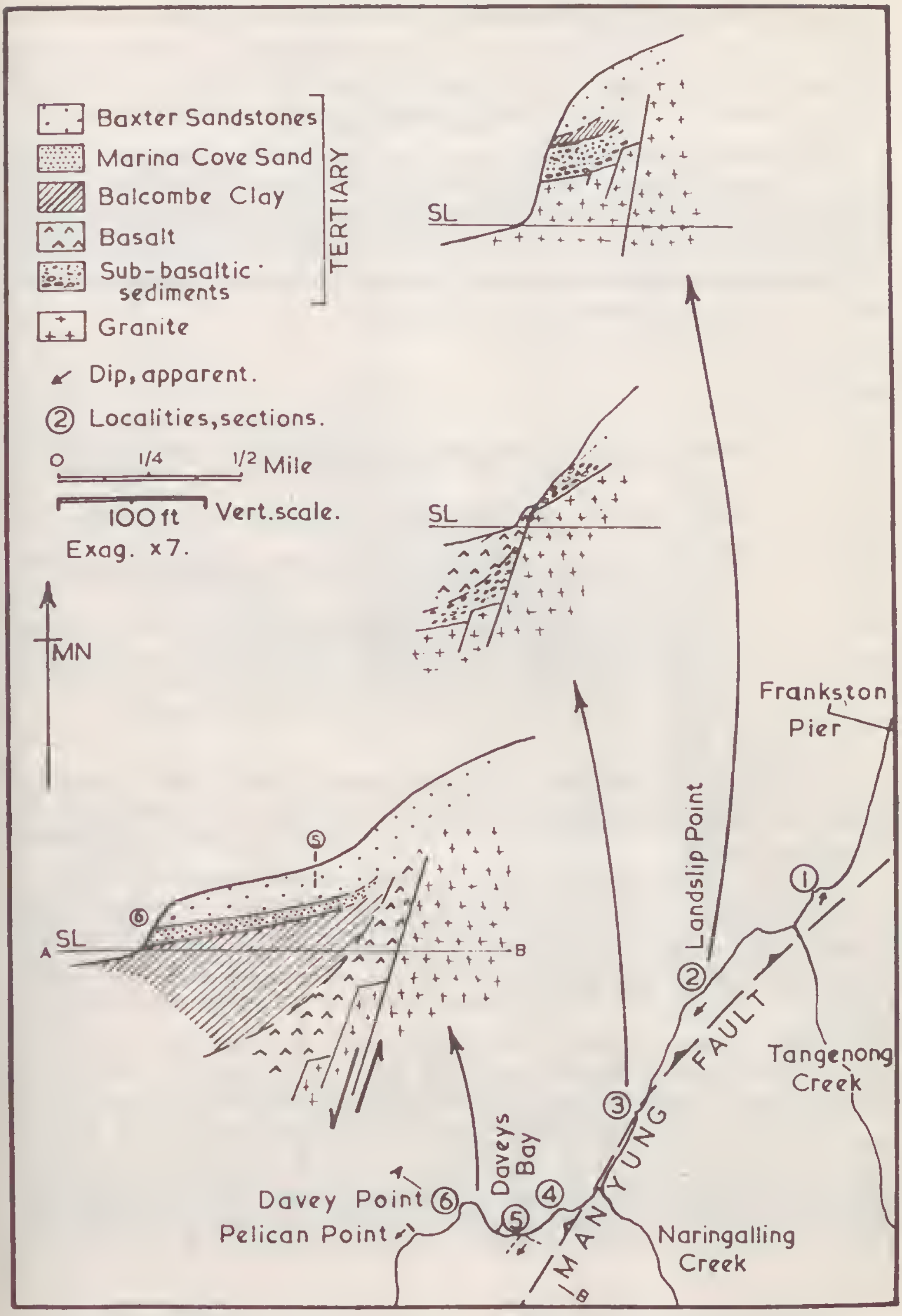


FIG. 2—Locality map of the coast between Frankston and Pelican Point showing three cross-sections.

300 ft, however, only a thin sand layer overlies the weathered granite. Three small creeks in this area provide exposures of strata underlying the ferruginous sands. Ballar Ck, to the north, shows some weathered olive-grey clay or silt, but a carbonate concretion with Tertiary fossils was also found. Calcareous silt with Tertiary mollusca has been previously recorded from this locality (Kitson 1900, p. 10).

The basalt exposed in the bed of Dennant Ck (see Fig. 4) approaches to within ¼ mile of the coast, where at Locality 7A some grey calcareous silty clay occurs. This contains Tertiary fossils (mainly mollusca) and layers of carbonate concretions. Its junction with the basalt is obscured and is considered to be a fault, downthrown to the NW.

The calcareous silt forms the bed of Dennant Ck down to about 200 yds from the coast where the following section is exposed.

SECTION 7B: DOWNSTREAM DENNANT CK

Bed	Thickness	Description
(e)	4′ +	Boulders, pebbles, and sand detritus. Not ferruginous or cemented, and similar to the present creek debris. (Valley-side remnant of a ? Quaternary creek-level)
(d)	*c.* 8′	Coarse sands with steep cross-bedding. Mottled yellow, red, and purple. Cemented with limonite along irregular bands.
(c)	3′	Interbedded fine and coarse sands, red to yellow colour and partly cemented with limonite. Fine quartz gravels at the base, which is scoured. Pebbles of clay, basalt, and ? granite also occur.
(b)	5′	Yellow-brown very fine sand. Homogeneous except for rare clayey pellets near the top. Strongly and irregularly ferruginized at the base.
(a)	1′	Yellow clayey silt. Some 30 yds upstream, a better exposure of this bed grades into the underlying grey calcareous clayey silt with Tertiary mollusca.
		Base level is the bed of the creek which is about 20′ above sea level.

The only Tertiary outcrops between this section and the mouth of the creek are those of ferruginous coarse sands similar to bed 7B(d). At the headland S. of Dennant Ck these cross-bedded, coarse sands are overlain by finer massive sands of unknown extent.

Grices Ck, the next stream to the south, shows a similar sequence of exposures. Its headwaters are in sands and weathered granite, which may be followed down to the foot of a small private dam (near Albatross Av.). At this point, the granite is overlain by a thin gravel or weathered conglomerate and a few feet of coarse granite wash, which underlies weathered basalt. The sequence is thus closely comparable with the other Lower Tertiary exposures nearer Frankston (Sections 1 and 2).

The basalt thickens downstream, and forms the bed of the creek until some 150 yds from the coast. Here at Locality 8, it is succeeded by calcareous clayey silt with carbonate concretions and abundant Tertiary fossils (Fig. 3 and 4).

The structure is essentially that of a normal fault in the vicinity of the silt-basalt junction. The strong upward drag on the clayey silt has resulted in high dips (up to 60°) near the fault. These steadily decrease downstream, away from the structure. Such a fault was suggested by Singleton (1941, p. 82). Keble, who apparently did not see the upstream exposure, thought the dips to be initial, and thus gave a misleading section along the creek (Keble 1950, Fig. 33).

The thicknesses of the fossiliferous exposures in Grices Ck are as follows:

Section No.		Thickness
8B	Downstream section	c. 50′
	Covered Interval	c. 70′
8A	Upstream section	c. 30′

The thickness given for the covered interval is based on the assumption that the section is not further disturbed by faulting.

S. of Grices Ck, the low coastal cliffs consist of similar calcareous silts, which have an apparent dip to the north. However, detailed measurement of the sequence was prevented by the lack of good exposures. The silt forms an off-shore platform, a few feet below low tide level, and may be traced S. to Manyung Rocks. On the

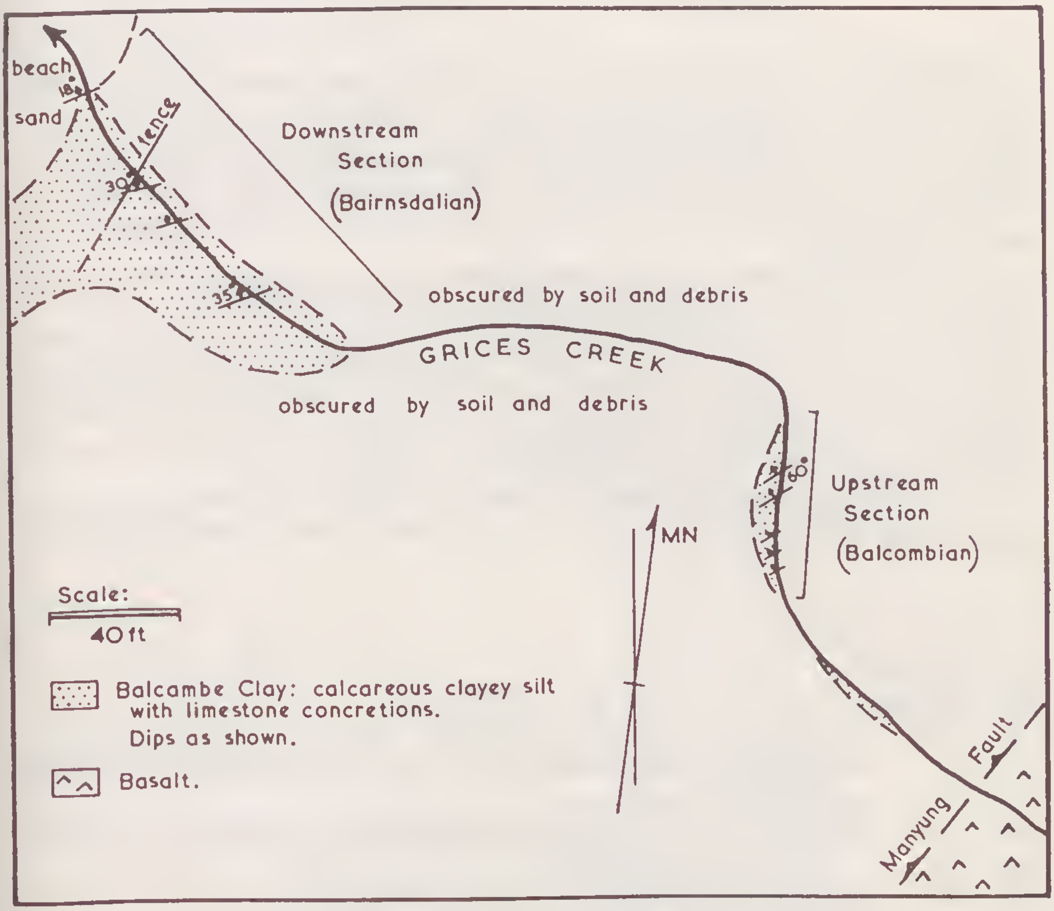


FIG. 3—Grices Ck exposure of the Balcombe Clay.

N. side of this point a landslipped block forms the shore platform. The beds dip about 30° inland, are not internally disturbed, and have the following true-thicknesses.

SECTION 9: MANYUNG ROCKS

Bed	Thickness	Description
(h)	6′ +	Lightly ferruginous coarse clayey sands, grading up into mottled red and yellow clayey sands and sandy clays.
(g)	c. 3′	Yellow-brown, friable, very fine sand.
(f)	3′	Cemented brown, very fine sand. Ferruginous moulds of lamellibranchs and echinoids along distinct horizons.
(e)	c. 3′	Brown fine clayey sands with some clay pellets. Irregularly layered.
(d)	6″	Brown and yellow sandy silt. Strongly and irregularly ferruginized and cemented.
(c)	6″-1′	Olive-yellow and brown clayey silt.
(b)	c. 6′	Grey, non-calcareous clayey silt. Rare carbonate concretions near the base.
(a)	4′ +	Grey calcareous clayey silt with layers of carbonate concretions. Abundant Tertiary mollusca.

This sequence is comparable with that of downstream Dennant Ck (7B); with beds 9(a) to (c) equivalent to bed 7B(a), beds 9(d) to (g) equivalent to bed 7B(b), and the coarse poorly sorted sands of bed 9(h) equivalent to beds 7B(c) and (d). The presence of echinoids in bed 9(f) indicates that marine conditions persisted after the deposition of the clayey silts, and that scarcity of fossils in the very fine sand unit has probably resulted from the removal of carbonate due to leaching of the beds.

S. of Manyung Rocks the calcareous silt forms a shore platform some 270 yds long, the southern part of which shows the beds steeply inclined to the NW. The structure is a steep monocline or fault lying at an acute angle to the coast (Fig. 4, 5). It is proposed to call this structure the Manyung Fault, even though at this locality, as at Grices Ck, the drag on the beds is sufficiently strong so as to create a monocline. The Manyung Fault can be traced N. through Grices and Dennant Ck to Daveys Bay and Locality 3. The northerly dip of the beds at Section 1 has probably also been caused by this structure.

A small jetty about 150 yds S. of Manyung Rocks is a convenient base for measurement of the upturned strata forming the shore platform. Thus the complete section S. of the jetty is as follows:

SECTION 10A: S. OF MANYUNG ROCKS

Bed	Horizontal Thickness	Description
(g)	—	Grey calcareous clayey silt with Tertiary mollusca and layers of carbonate concretions. Worm burrows and small pyrite segregations are locally abundant.
(f)	1′-3′	Discontinuous (? faulted) layer of fine sand.
(e)	8′	Carbonaceous silt. Plant remains include ligneous wood, leaves, and seeds. Iron sulphide is abundant.
(d)	c. 10′	Coarse sand with carbonaceous matter. Much obscured.
(c)	6″-1′	Prominent coarse sandstone.
	6′	Covered interval.
(b)	2′-3′	Coarse sand and fine gravel with some ligneous wood. Minor faults disturb the bed.
(a)	c. 55′	Strongly weathered basalt.
		The bedrock is of Mesozoic arkoses and mudstones but the contact with the basalt is obscured.

Beds 10A(b) to (e) dip more than 70° to the NW. For convenience, the inclined layers of carbonate concretions in bed 10A(g) were measured along the beach, and not perpendicular to the bedding. Thus, beginning from the seventh pile down the jetty from the boatshed, and proceeding S. on an azimuth of 203°T (195° Magnetic), the positions of the beds and samples are as follows:

SECTION 10A, BED (g):

Position of Concretion Layer	Position of Sample	Sample No.	Comments
Distances in Ft			
32			
	65	13	
66			Dip 15° on az. 300°T (approx.)
	84	12B	
	101	12A	
	118	12	
120			
139			
153			Prominent Layer
	155	11	
169			Dip 52° on az. 332°T
	194	10	
195			
208			
216			
	229	—	Black carbonaceous bed with light grey worm burrows; about 6″ thick
	232	9	
233			Prominent Layer. Dip 57° on az. 337°T
246			
	249	8	
250			
278			Dip 60° on az. 340°T
	279	7	
289			
	304	6	
	311	5	
—			Several less conspicuous layers of concretions occur in this interval
	328	4	
	330	3	Non-calcareous dark grey clayey silt

From 331′ to 340′ bed (e) or (f) of this section begins.

About 40 yds N. of the jetty the calcareous silts have a slight south-easterly dip (? backtilt) and are overlain by sands forming cliffs which rise some 70 ft above sea level. A small but steep gully about 70 yds N. of the jetty best exposes the upper strata so that the composite section is as follows:

SECTION 10B: S. OF MANYUNG ROCKS

Bed	Thickness	Description
(d)	40′ +	Brown, red, and yellow, coarse sands with minor gravels and finer sands. Steep cross-bedding. Scoured at the base. The basal 5′ is strongly cemented with limonite.
(c)	6′-10′	Yellow, brown, or red very fine sand. Cemented with limonite near the base.
(b)	6′	Grey non-calcareous clayey silt. Strongly jointed, and with a yellow mineral infilling or staining the joint planes.
(a)	17′	Grey calcareous clayey silt with layers of carbonate concretions and abundant Tertiary mollusca. This bed extends below sea level.
		The layers of concretions are spaced as follows (measured above sea level): 1′-3′ poorly developed; 4′ prominent; 5′; 7′; 10′ prominent; 13′ rare; and 17′. Sample 10B/1 (foraminiferal study) was taken at 9′ above S.L.

Beds 10B(a) to (d) can be directly compared with beds in the Manyung Rocks and downstream Dennant Ck sections. The strata underlying the fossiliferous silt, i.e. beds 10A(b) to (c), are probably the continuation of similar fluviatile deposits recorded by Kitson (1900, p. 6) as overlying the basalt in Grices Ck.

A short distance S. of Section 10A, weathered granite occurs high in the cliffs and is overlain by ferruginous and lightly cemented coarse to fine sands. The contact is obscured by slumping but no evidence for the occurrence of very fine sand, similar to bed 10B(c), could be found. The sands, however, are similar to those forming the overlying bed 10B(d). If these observations are correct, then movement on the Manyung Fault took place after the deposition of bed 10B(c) and probably during the deposition of the overlying poorly sorted and generally coarse sands.

About 600 yds S. of Manyung Rocks, at Locality 11, the bedrock of Mesozoic rocks forms much of the shore platform, while the overlying basalt forms the cliffs. The strata dip S. at about 15° and are as follows:

SECTION 11:

Bed	Thickness	Description
		Ferruginous sands and rubble. Mostly landslipped.
(f)	*c.* 1′	Banded brown carbonaceous clay and silt with poorly preserved plant remains.
(e)	2′	Light and dark brown very fine sand and silt.
(d)	1″-4″	Brown, very coarse sand (grit), and fine gravel. A few weathered felspars present.
(c)	1′-1′6″	Yellow, very fine sand with coarse sand layers especially towards the base.
(b)	1′	Red and brown coarse sands and fine gravels. Granules of reef quartz, sandstone, and shale.
	c. 10′	Covered interval.
(a)	40′-50′	Strongly weathered basalt. Mostly vesicular and altered to clay. A gravel bed is present near the base and another (2′ thick) occurs near the top. Pebbles are of Palaeozoic slate, sandstone, and reef quartz.

Beds 11 (b) to (f) are the continuation of similar fluviatile beds in the previous section, i.e. beds 10A(b) to (e).

At the beach end of Sunnyside Rd, the low headland is formed mainly of slumped ferruginous sands. Beneath this abundant debris, the shore platform consists of Mesozoic sediments with a thin cover of weathered basalt containing veins of siderite. The basalt as well as the Mesozoic sediments appear to be slightly faulted at this locality.

S. of Sunnyside Beach, granite cliffs rise over 100 ft above sea level and extend for ¾ mile along the coast. They are overlain by loose granite wash and windblown sand. Ferruginous sands are rare except towards the south.

At Locality 12, on the SW. end of Beleura Hill, the following exposures were recorded. Dipping S., off the granite cliffs, and occurring on the beach, are many large blocks of coarse Tertiary sediment. These consist of ferruginous and strongly cemented conglomerates, and cross-bedded coarse gritty sandstones. The pebbles are of Palaeozoic sandstone, reef quartz, shale, and spotted slate. The sediments probably belong to the lower Tertiary (pre-marine) deposits, rather than the upper Tertiary (post-marine) sands. The cliffs behind Mills Beach are covered by ferruginous debris, and do not provide any further structural or stratigraphic information.

On the S. side of Tanti Ck (Locality 13), and 100 yds around the point, the following composite section was measured.

SECTION 13:

Bed	Thickness	Description
(c)	*c.* 15′	Coarse sands and clayey sands, cross-bedded. Mottled, ferruginous and partly cemented. Lower boundary irregular and trangresses the bedding.
(b)	*c.* 20′	Coarse sands with steep cross-bedding. Ferruginous but mainly friable. A 4″ thick, finely laminated clay and sand bed occurs near the top and may be traced over 60 yds. The lower 10′ of bed (b) is largely obscured by scree. The base of the bed is strongly cemented with limonite and has a 3-5° dip to the south.
(a)	2′	Yellow-olive very fine sand.

It is considered that beds 13(a) and (b) are probably the continuation of similar beds 10B(c) and (d) at S. of Manyung Rocks.

About ¼ mile farther S., another cliff section shows yellow-brown coarse sands at the base, followed by mottled silty sands with some gravel and a thin layer of clay, overlain by red and yellow coarse sands to 20 ft above sea level. These beds are similar to beds 13(b) and (c) of the previous section.

In view of the S.-dipping nature of beds at Localities 12 and 13, and the probable rise in the sequence towards the south, it is suggested that a tilt or down-warp to the south or west, may occur in the vicinity. The last three exposures are the only ones available along this stretch of coast.

The mottled ferruginous coarse sands continue around the small bay to Schnapper Point where they form cliffs about 30 ft high. The hard ferruginous shore platform is overlain by blocks of similarly cemented sands. From Schnapper Point S. to Fossil Beach the land surface rises slowly to about 100 ft and the sequence of grey clayey silt, very fine sand, and cross-bedded coarse sands also reappears. The parallelism of the surface with the underlying strata shows that little physiographic alteration has occurred since their deposition. The beds have a slope of less than half a degree to the north, so that the very fine sand unit is brought up to sea level ½ mile S. of Schnapper Point, and the grey clayey silt at Fishermans Beach. From here to Fossil Beach this non-calcareous clayey silt forms the shore platform, and is overlain by the ferruginous debris of the succeeding units.

On the S. side of Fisherman Point, at Locality 14, the height of the units is as follows: the grey clayey silt rises to about 3 ft above sea level and is overlain by 15 ft of very fine sand. This is succeeded by a 4″ layer of coarse sand passing up into ferruginous coarse and medium sands, which rise to some 35 ft above sea level and are covered by buckshot gravel.

The coastal section from Marina Cove to Section 23 is illustrated in Fig. 6. Important and typical sections, however, are described here in detail.

At the N. end of the small Marina Cove beach, the following section was recorded:

SECTION 15: MARINA COVE

Bed	Thickness	Description
(j)	1′ 6″	Grey sandy soil.
(i)	6″	Hard ironstone concretions (Buckshot gravel).
(h)	20′	Mottled and ferruginous sandy clays and clayey sands. Partly cemented. Two thin (1″) clay beds near the base.
(g)	2′	Ferruginous and strongly cemented coarse sands. Cross-bedded.
(f)	6′	Yellow and brown coarse sands, with steep cross-bedding.
(e)	c. 3′	Yellow to white fine sands, cross-bedded and stained with limonitic bands.
(d)	3″	Yellow-brown coarse sand, scoured into the underlying bed.
(c)	17′	Yellow very fine sand, stained with brown limonitic bands.
(b)	3″	Red to purple clayey sand.
(a)	9′	Grey non-calcareous clayey silt, strongly weathered and obscured by cliff debris. It extends below sea level.
	5′	Beach sand, covered interval.

On the S. side of the next headland, at Locality 16, the following section occurs.

SECTION 16:

Bed	Thickness	Description
(k)	6″-1′	Grey sandy soil.
(j)	6″	Buckshot gravel.
(i)	5′	Mottled yellow, red, and brown clay.
(h)	13′	Yellow-brown limonite-cemented sands with irregular patches of white and yellow friable sands and sandy clays.
(g)	3′	Ferruginous and strongly cemented coarse sands. Cross-bedded.
(f)	2′	Coarse sand with fine sand layers. Cross-bedded.
(e)	2′ 6″	Light grey to brown very coarse sand and fine gravel. Steep cross-bedding.
(d)	c. 3′	Discontinuous layers of light yellow fine sands, mottled bright yellow in part and with cross-bedded coarse sand layers.
(c)	c. 3″	Coarse sand and grit, with small pebbles of shale. Scoured at the base.
(b)	10′	Yellow to olive very fine sand. Thinly banded with brown limonite towards the top and containing limonite replaced worm burrows. Possibly cross-bedded.
(a)	19′	Grey non-calcareous clayey silt extending below sea level. Limonite or a yellow mineral infilling and coating the numerous joints. A few carbonate concretions occur at sea level.

Beds 16(a) and (b), and the first entry of coarse sands, 16(c), can all be easily recognized and followed in the field. The overlying beds, however, are cross-bedded, discontinuous, and with a variable degree of cementation. This creates difficulty in exact correlation between sections, although a broad variation in texture and cementation can be discerned (cf. Section 16 with Sections 15, 17, and 20).

The Fossil Beach area is strongly landslipped. Here the grey non-calcareous clayey silt is underlain by a similar but calcareous, and richly fossiliferous silt, extending for a total length of over 400 yds. At the N. end of this exposure, the non-calcareous silt is 27 ft thick, whereas at the Fossil Beach Section (17) it is only 15 ft thick. This reduction may be due to the landslip. The Fossil Beach Section is taken about 150 yds N. of the drive down to the beach. This was first described in detail by Singleton (1941, p. 27), but because the beds dip N. at about 15°, it is possible to observe beds below Singleton's bed (h). Furthermore, samples kept from the Bores (Moorooduc 4-7), put down at the beach end of the drive, have been re-examined and the lithologic descriptions (for Bore 6) modified. The information recorded from this bore has been used to complete the measured section, but because its location is over 150 yds away from the cliff section, the true thickness of the calcareous clayey silt remains unknown.

SECTION 17: FOSSIL BEACH

Bed	Thickness	Description
	3′ +	Loose rubble of ferruginous sands and clays.
(w)	6′	Brown ferruginous and cemented coarse sands.
(v)	4′	Yellow coarse to very coarse sand.
(u)	2′	Dark brown ferruginous and strongly cemented very coarse sand.
(t)	6″	Brown friable coarse sand.
(s)	9′	Light yellow to reddish, very fine sand. Stained brown along thin bands.
(r)	6″	Olive-yellow silty sand grading into overlying bed. Sharp lower contact.
(q)	15′	Grey non-calcareous clayey silt, stained yellow along joints and containing crystals of selenite. Rare carbonate concretions in the lower part. Topmost foot of the bed oxidized to an olive grey colour.
	c. 6″	Grey calcareous clayey silt with pyrite and abundant selenite. Numerous slickensides. The layer is uneven and probably marks the sole of a landslip.
(p)	12′ 6″	Grey calcareous clayey silt with pyrite and Tertiary mollusca.
(o)	6″-9″	Prominent layer of carbonate concretions.
(n)	6″-1′	Grey calcareous clayey silt, as for (p).
(m)	c. 1′	Grey calcareous clayey silt with numerous burrows up to ¾″ thick.
(l)	2′	Grey calcareous clayey silt, as for (p).
(k)	6″-9″	Sparse carbonate concretions.
(j)	3′	Grey calcareous clayey silt, as for (p).
(i)	6″	Sparse carbonate concretions.
(h)	3′	Grey calcareous clayey silt, as for (p), and extending below sea level.
Bore information:		
(g)	36′	Grey calcareous clayey silt with some carbonate concretions.
(f)	16′	Sandy clay and clayey sand.
(e)	24′	Fine sands.
(d)	2′	Carbonaceous clay.
(c)	4′	Coarse sand.
(b)	33′	Carbonaceous clay.
(a)	19′ +	Basalt.

In Bore 7, situated some 60 ft to the south, the basalt comes within 12 ft of the surface, is some 174 ft thick, and overlies weathered granite. In Bore 5, located 70 ft farther S., the basalt is only 74 ft thick. The sudden change in lithology between Bores 6 and 7, as well as in the cliff sections on either side of the structure, indicates the presence of a fault. This structure was first suggested by Singleton (1941, p. 83), and it is proposed to call it the Fossil Beach Fault. Disturbance or drag of the beds in the fault zone has probably given rise to the change of basalt thickness (Bores 7 and 5), and in an upturned sandstone layer projecting from the shore platform several yards S. of the southernmost exposure of the calcareous silt. As a result, thicknesses recorded from Bores 6 and 7 have to be taken as approximate only. The fault strikes at about 30°T with a downthrow to the NW.

At a small point at the S. end of Fossil Beach, weathered columnar basalt, with veins of siderite, forms the shore platform. Columnar basalt can also be seen forming two small islands exposed only at low tide. About 150 yds S. of the point, at Locality 18, the following sequence occurs.

Section 18:

Bed	Thickness	Description
		Irregular slumped surface with mottled and ferruginous fine to coarse sands.
(g)	2′ +	Grey and yellow clayey silt with a little coarse sand. Partially cemented in layers with a yellow mineral. Gradational lower boundary with *c.* 2″ of very coarse sand and elongated mud pellets.
(f)	9′	Grey and yellow, clayey, very coarse sand with a few elongated mud pellets. Partial cementation by a yellow mineral towards the top.
(e)	11′	Grey and yellow fine sand; structurally homogeneous.
(d)	*c.* 6″	Horizontal layer of grey coarse sand with gradational boundaries.
(c)	9′	Grey and yellow fine sand; structurally homogeneous.
(b)	9″	Grey very coarse sand in a horizontal layer.
(a)	1′	Grey fine sand.
	10′	Beach sand and cliff debris. Covered interval.

Nearby a sea-level exposure of basalt is overlain by coarse sands and fine gravels with carbonaceous plant remains, including ligneous wood. Two logs of such wood occur, *in situ*, at 10 ft above sea level.

Beds 18(e) to (g) may be followed S. along the coast to a basalt point at Locality 19 (Harmon Rocks). The section given here records the basalt at the point in conjunction with the strata of the cliffs immediately behind.

Section 19: Harmon Rocks

Bed	Thickness	Description
(f)	*c.* 35′	Red, yellow, and brown, mottled and partly cemented coarse sands. Steep cross-bedding. Beds of finer sands and some small pebbles occur near the base which shows scour.
(e)	2′	Yellow, partly ferruginous, very fine sand.
(d)	5′	Grey and partly ferruginous clayey silt with some coarse sand grains.
(c)	5′	Grey and mottled clayey very coarse sand.
(b)	16′	Yellow fine sand.
	20′	Covered interval. Slumped material.
(a)	19′	Hard basalt, weathered and soft towards the top. Many horizontal joints, several large vertical joints, occasionally with siderite veins.

Hall and Pritchard (1901, p. 40) stated that 'grits and conglomerates can be traced passing under a small mass of basalt', when referring to this point. No evidence for such an occurrence could be found.

At the steps or path, about 200 yds S. of the previous section, a large landslipped block at beach level, and the side-cutting of the path, enabled the following section to be recorded.

SECTION 20:

Bed	Thickness	Description
(k)	3′	Sandy soil with a well developed A horizon of leached white sand, and a B horizon of light brown clayey sand.
(j)	6′	Lightly mottled sands. Note: beds (j) and (k) wedge out to the north where bed (i) comes to the surface. The latter bed has a dip of 2-3° S. along the coast.
(i)	1′	Buckshot gravel.
(h)	5′	Ferruginous and mottled sandy clays.
(g)	9′	Ferruginous, cemented, and mottled clayey sands near the base, overlain by sands and sandy clays grading into bed (h).
(f)	15′	Ferruginous coarse sands and fine gravel, with some intercalations of fine sands. Cross-bedded.
(e)	2′ 6″	Yellow and red very fine sand.
(d)	1′	Grey clayey silt, mottled in part.
	c. 52′	Covered interval.
(c)	c. 5′	Sandy gravel. Steeply cross-bedded with northerly dips.
(b)	4′	Carbonaceous silt.
	3′	Beach, covered interval.
(a)	—	Strongly weathered basalt below sea level overlain by 2′ + of sandy gravel with pebbles of reef quartz and sandstone. Severe slipping occurred within the basalt which is now weathered to clay.

About 150 yds S. of this, at Locality 21, the cliff section is as follows:

SECTION 21:

Bed	Thickness	Description
(i)	25′ +	Lightly mottled sands and clayey sands. Section inaccessible.
(h)	1′	Buckshot gravel.
(g)	5′	Coarse sands, cross-bedded and with a sharp lower boundary.
(f)	2′	Yellow and red very fine sand.
(e)	8′	Grey and mottled clayey silt.
(d)	2′	Ferruginous and partially cemented very coarse sand with poorly defined boundaries.
(c)	c. 38′	Light yellow, homogeneous, fine sand.
(b)	2′	Coarse to fine sands with some granules, grading into bed (c).
(a)	4′	Carbonaceous silt.
	6′	Covered interval. Beach sand.

Beds 21(a) and (b) are found some 30 yds N. of the rest of the section. Beds 21(e) to (c) can be traced S. along the coast, as they dip steadily in this direction, probably as a result of a backtilt on the Chechingurk Fault (Keble 1950, Fig. 58). However, cementation of the overlying sands decreases in intensity to the south, and hindered by severe slipping it becomes impossible to differentiate these beds further than 50 yds S. of Section 21.

At the base of a steep gully (near Hawker St), Locality 22, the continuation of bed 21(e) comes to within a few feet of sea level, bed 22(e). Here the lower beds 22(a) and (b) were measured in the cliffs 40 yds N. of the gully whereas the best exposure of bed 22(c) is at the gully mouth.

SECTION 22:

Bed	Thickness	Description
(d)	15′ +	Light grey, clayey, fine and medium sands.
	c. 20′	Coarse to fine clayey sands, not *in situ*.
(c)	10′ +	Grey clayey silt with a little coarse sand. Non-calcareous and strongly jointed, with a yellow mineral staining the joint planes. Worm burrows, impressions of bryozoa, and internal moulds of Tertiary mollusca present.
(b)	2′ 6″	Ferruginous very coarse clayey sand.
(a)	2′ +	Fine sands to below sea level.

S. of this locality a large landslipped area consisting of ferruginous sandstone debris, projects slightly into Balcombe Bay. On the S. side of this the densely vegetated cliffs are formed of similar ferruginous and mottled sands, overlain by buckshot gravel at the surface. The cliffs continue for a couple of hundred yards until a damp sandy zone near Alice St defines the channel of the Chechingurk Fault. Strongly weathered basalt forms the upthrown southern side of the fault, which strikes at about 110°T.

Some 300 yds S. of the fault, at Locality 23, the following section shows the reappearance of the sub-basaltic deposits:

SECTION 23:

Bed	Thickness	Description
		Buckshot gravel at the surface.
(b)	c. 25′	Weathered basalt, ferruginous above the lowest 5′.
(a)	5′-7′	Coarse quartz sands and gravels, with pebbles of Palaeozoic reef quartz, weathered shale and sandstone.
	25′	Covered interval of beach sand and other detritus.

The land surface continues to decline S. to Balcombe Ck, and no further exposures can be seen until the granite of Balcombe Point is reached. E. of this, the granite in the shore platform is overlain by up to 80 ft of undifferentiated grey and yellow clayey sands of probable Quaternary age.

Description of Stratigraphic Rock Units

The general sequence of rock units in the Mornington District is as follows:

Baxter Sandstones
Marina Cove Sand
Balcombe Clay
Harmon Rocks Sand Bed
Mt Martha Sand Beds
'Post-Basaltic Terrestrial Sediments'
Older Volcanics
'Sub-Basaltic Sediments'

Description of these units is based on the current work carried out in the Mornington District, but reference to other areas on the Mornington Peninsula is also made, wherever appropriate.

The drillers-logs of bores in the Mornington District were studied, but except for those at Fossil Beach, no bore samples are available so that reliable stratigraphic

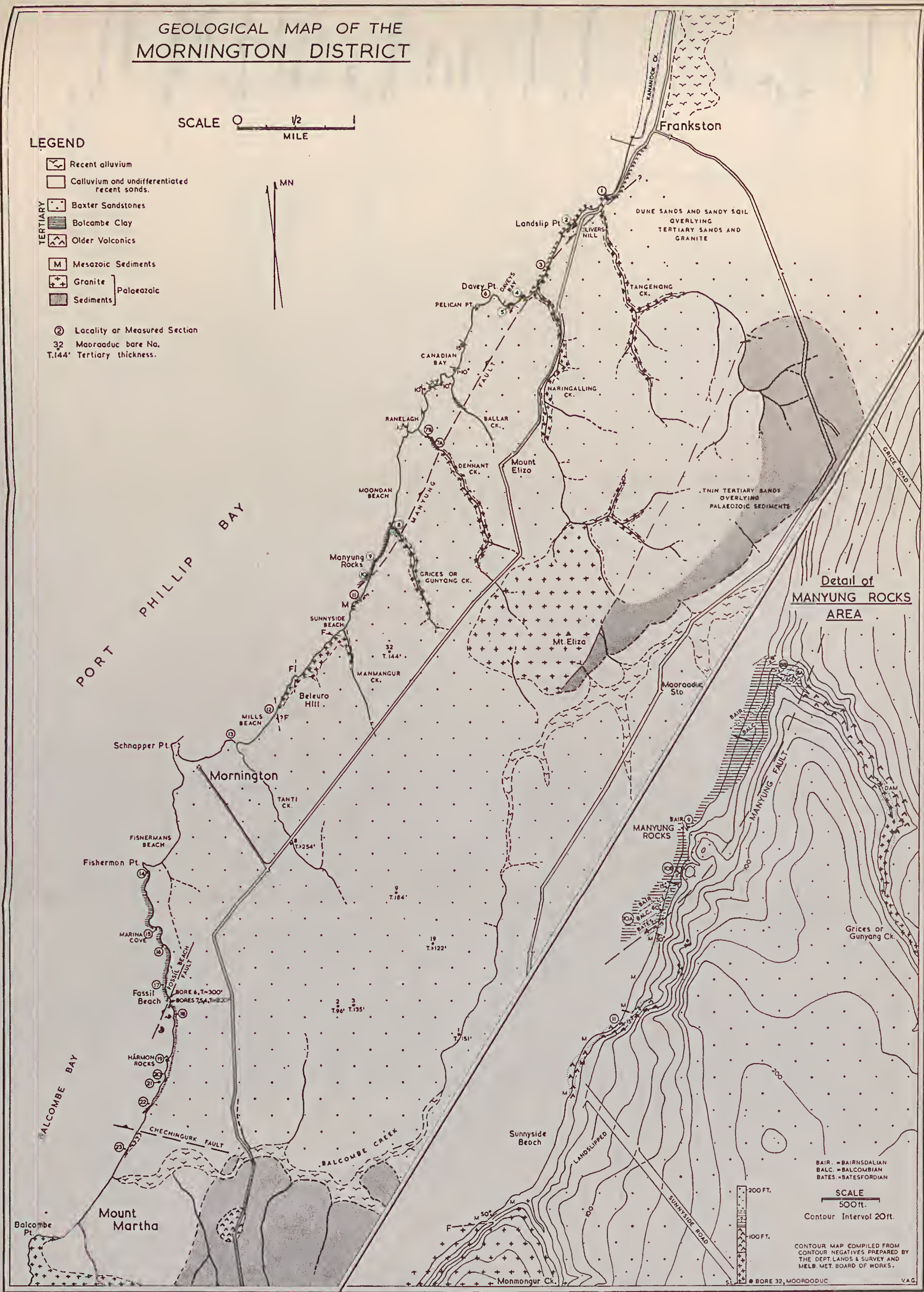


FIG. 4—Geological Map of the Mornington District.

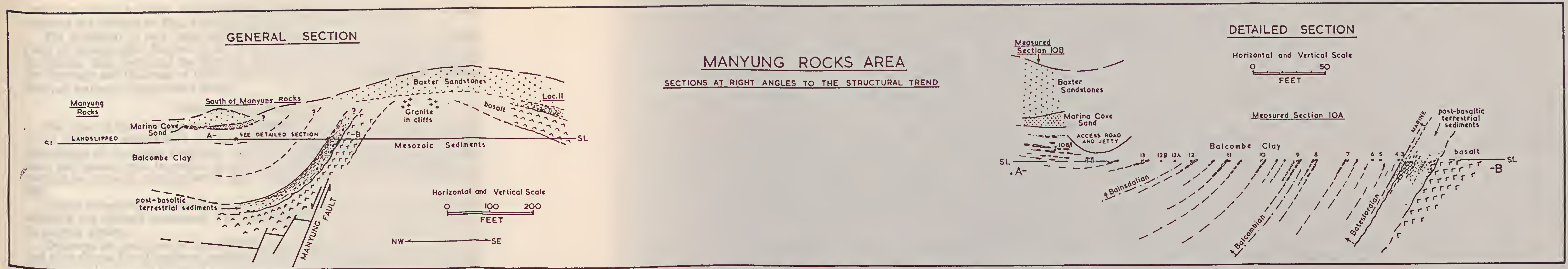


Fig. 5—Coastal sections of the Manyung Rocks area.

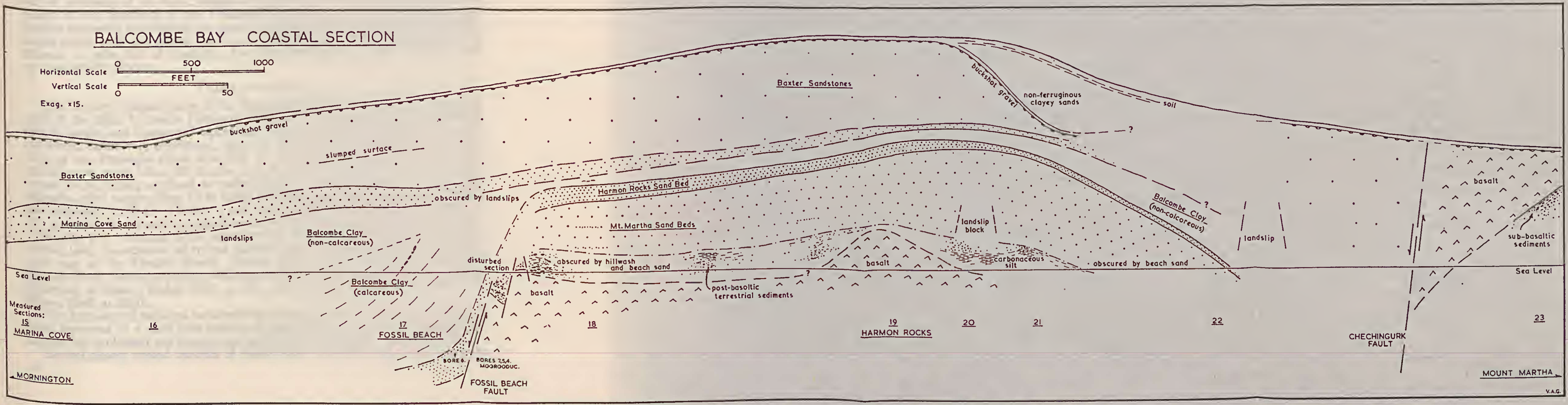


Fig. 6—Coastal section from Marina Cove to Locality 23.

correlation cannot be made. The positions of bores that reveal a significant Tertiary sequence are marked on Fig. 4 along with the total Tertiary thickness.

The definition of rock units has followed the rules set out in the Australian Code of Stratigraphic Nomenclature (3rd Ed. 1959) with the addition that the Mt Martha Sand Beds and the Harmon Rocks Sand Bed are specifically defined. The lithology and thickness of these units are known, but their limited areal extent does not warrant a formational status.

'Sub-Basaltic Sediments'

The base of the Tertiary succession consists of a variable sequence of poorly sorted sediments, usually with a conglomerate at the base. This consists of pebbles and cobbles of micaceous sandstone, quartzite, spotted slate, graptolitic shale, and some reef quartz, with interstitial granitic quartz grit and weathered felspar. It is overlain by coarse to medium sands, finer sandy silts, and occasional carbonaceous clay.

Unless subsequently ferruginized and cemented, the sediments are poorly consolidated and strongly weathered. They are usually less than 30 ft thick, and may be entirely absent.

Outcrops are restricted to the coastline near Frankston (Localities 1, 2, 3), in and S. of Grices Ck (Localities: upstream from 8, 11 and probably 12), and near Mt Martha (Locality 23). Inland they have been recorded in bores (e.g. Moorooduc 2 and 8).

The variable nature of the lithology and thickness, the poor sorting, and the lack of continuity of the strata, indicate a fluviatile environment of deposition. The source of the sediments is the Palaeozoic basement, with the Ordovician and Silurian sediments contributing the gravel, and the granites contributing most of the coarse quartz sand and felspar (now clay). Plant remains from similar deposits at Berwick, 15 miles NE. of Frankston, have been described by Deane (1902). Their age is probably Eocene.

Older Volcanics

The Tertiary volcanic rocks of the Mornington Peninsula form one of the type areas of the Older Volcanics (Edwards 1938, p. 78). They consist of a variety of olivine basalts and fragmental equivalents, sometimes with intercalated fluviatile sediments. Extensively distributed, they are absent only from the narrow central horst of the Peninsula (from Red Hill N. to Cranbourne) and from the high granitic areas of Mt Eliza, Mt Martha, and Dromana. N. of Mt Eliza the volcanics appear to be largely confined to valley flows but farther south they are more extensive, often ranging from 50 to 150 ft thick and occasionally to several hundred feet. However, S. of the Flinders Fault, bore information indicates an excess of 850 and 1,300 ft of basalt at Cape Schanck and Flinders respectively (Keble 1950, p. 26, Fig. 19). Although Keble separates this lava field and calls it the 'Flinders plateau lava', the absence of typical plateau lavas (tholeiitic) calls for a simpler term such as the Flinders Basalt (Jenkin 1962, p. 13). Movement along the Flinders Fault, contemporaneous with lava extrusion, would account for the sudden thickening of basalt (Jenkin 1962, p. 12). The volcanics probably extend W. of Selwyn Fault at depth.

The extrusion of the lavas occurred sub-aerially in the form of many, often thin flows, separated by a small time interval of weathering and erosion. Sometimes the interval was prolonged and sands, clays and lignite accumulated, as at Hastings.

Several closely related varieties of basalt occur. Textures range from coarse to fine grained and often with much interstitial glass. Their petrology has been described by Edwards (1938) who distinguished three main types:

1. CRINANITES: Doleritic olivine-analcite basalts which have a few phenocrysts of olivine set in a coarsely ophitic matrix of titanaugite and labradorite, with some ilmenite, needles of apatite, and interstitial analcite. Aegerine and biotite may also be present. This type is common towards the south.

2. MOOROODUC TYPE: Titanaugite basalts common in the north of the area but present also at Flinders and Cape Schanck. They are medium grained with olivine phenocrysts in a matrix of ophitic titanaugite and labradorite, and abundant interstitial glass. Chilled phases with more glass also occur.

3. FLINDERS TYPE: This is widespread throughout the area and is characterized by the absence of titanaugite and ophitic structure. Olivine is present as phenocrysts in a matrix showing flow structure, and consisting of augite, labradorite, iron ore, and green glass.

In the south, iddingsite basalt and glassy olivine-basalt are also occasionally present.

These lava flows and pyroclastics are usually strongly weathered, and may be mistaken for other sedimentary deposits. The weathering products are variable, depending largely on past and present environments. Iron ore minerals (mainly ilmenite) and possibly apatite, have escaped decomposition, which has resulted in clays such as montmorillonite and kaolinite. Halloysite is also known to have formed, and may be related to the silicification of enclosed plant remains at Frankston (Gostin 1964).

At several localities in the Mornington District (Localities 2, 11, near 18 and 19) veins of a light grey to greenish grey dense mineral are found filling the joint planes in the basalt and in the fractured granite (at Landslip Point). The mineral is siderite, which may include a few crystals of green ?chamosite. The exteriar of the veins is usually altered to goethite and limonite. The siderite is probably of hydrothermal origin.

Although Keble (1950) indicated a few possible extrusion centres on his map, the source of most of the voluminous lavas on the Mornington Peninsula still remains unknown. The volcanic activity occurred some time before the Middle Miocene marine incursion, and palaeobotanical evidence given by Douglas in Jenkin (1962, p. 13) indicates a probable Oligocene age.

'POST-BASALTIC TERRESTIAL SEDIMENTS'

These are similar to the sediments found below and intercalated with the Volcanics, but are generally finer grained with a greater development of carbonaceous deposits.

At Balcombe Bay, S. of the Fossil Beach Fault, the irregular surface of the basalt is overlain by up to 15 ft of cross-bedded fine sandy gravels and quartz grits, often with logs of wood (lignite). Carbonaceous silt beds also occur. Deane (1902) has described some enclosed plants from these deposits.

The gravels contain pebbles of sandstone, shale, spotted slate, reef quartz, carbonaceous clay, and rare basalt. The sands consist of coarse granitic quartz and felspar (now weathered). The orientation of the cross-bedding was found to be variable. Although clear exposures are hard to find, these sands at Balcombe Bay appear to grade into the overlying unit of well sorted sands.

In the Manyung Rocks area, similar deposits to those described above, occur at Localities 10 and 11 (beds 10A(b) to (e), and 11(b) to (f)). They are less than 25 ft thick and underlie a thin bed of ? marine sand which is in turn overlain by a marine fossiliferous clayey silt of Batesfordian age.

Other post-basaltic gravel beds near Arthur's Seat (Dromana) have been described by Baker (1938) and Keble (1950, p. 32). The latter author's suggestion that these are contiguous with the pebble bed reported from Grices Ck (Kitson 1900) is unjustified considering the discontinuous nature of individual beds. At best, all these deposits represent a general fluviatile environment following the period of volcanic activity.

As with the sub-basaltic sediments, the origin of these deposits is mainly from the Palaeozoic sediments and granites, with the volcanic rocks, in this case, also providing some detritus. Much of this unit is of pre-Batesfordian age.

Mt Martha Sand Beds

The Mt Martha Sand Beds are proposed for all the fine, well-sorted sands and any included coarser sand beds, which overlie the post-basaltic terrestrial deposits at Balcombe Bay, and underlie the Harmon Rocks Sand Bed. The name Mt Martha beds has been previously informally used for the fossiliferous Tertiary sequence at Balcombe Bay. The Mt Martha Sand Beds are exposed S. of the Fossil Beach Fault and are recorded in the measured Sections 18, 19, 21, and 22. At Section 18 they include beds 18(a) to (e), but the base of the unit here is obscured. At Section 21 (Western Port, 1 mile, 067830) the sands are homogeneous throughout, and were recorded as bed 21(c), which best represents the unit. Other exposures include beds 19(b) and 22(a).

The Mt Martha Sand Beds consist predominantly of well to very well sorted, fine quartz sand, with a grey to yellow colour. The grains are generally rounded and lightly frosted. Grain size analyses are shown in Fig. 7, B, C, D, E, and Fig. 8. Representative grain size parameters are found in Table 1. For comparison, the analysis of underlying fluviatile bed 21(b) is included, Fig. 7A. The very coarse sand bed 18(b) is also near the base of the unit.

At Section 18, 4 samples above bed 18(b) were obtained for size analysis: Fig. 8A, B, C, D. Sample 18(e) 1, graph C, shows the presence of a small secondary mode in the coarse sand grade, whereas sample 18(d) taken one foot lower in the sequence shows this grade to be dominant. The strongly bimodal nature of this sample is difficult to explain in terms of our present knowledge regarding sedimentation, but several hypotheses are later considered. The bulk of this unit is texturally homogeneous, but fine horizontal lamination may occasionally be discerned, and the coarser sand beds are horizontal.

The mineralogy is predominantly of clear quartz, with rare grains of reef quartz and a little orthoclase felspar near the base. The quartz usually contains numerous inclusions and may show strain extinction. Heavy minerals are mainly ilmenite, zircon, tourmaline, and rutile.

The base of the Mt Martha Sand Beds is gradational with the fluviatile post-basaltic sands, but the upper limit is usually sharp, and may be easily traced along the coast. The unit is 20 to 40 ft thick, and is visible for about one mile, from Locality 22 N. to Fossil Beach, where it is cut off by the Fossil Beach Fault. It is recorded in the Fossil Beach bore, bed 17(e), and may extend a mile inland (Bore 2, Moorooduc). Keble (1950, p. 33) recorded these sediments suggesting their transgressive origin. A few feet of fine, clean sand S. of Manyung Rocks, bed 10A(f), and the medium, very well sorted sand bed at Landslip Point, bed 2(d), may be northern extensions of the Mt Martha Sand Beds.

The sediments have been mainly derived from the reworking of older Tertiary deposits.

ORIGIN: The good sorting and grain roundness of much of this unit suggests a littoral or nearshore environment (Inman & Chamberlain 1955, Friedman 1962). Although the sands may have achieved these characteristics under aeolian conditions the sub-horizontal nature of the beds suggests they are marine. Unfortunately, the presence of frosting is not as indicative of environment as was once thought (Kuenen & Perdok 1962).

The bimodal nature of some of the samples and the field observation that intermixed (and not laminated) sands occur up to a foot in thickness, implies that the origin of the sediment is probably more complex.

Because sand of medium grade is at a minimum, it is possible that this grade is not produced by the source rocks. However, the medium sand grade is present in the underlying sands, Fig. 7A, and forms the main component of the well sorted sand bed at Landslip Point (Fig. 9A), as well as of Quaternary dune and beach deposits near Frankston (see Fig. 9B, and Whincup 1944).

It is also possible for the two sand grades to have achieved their good sorting in separate areas, being redeposited together during periods of intense current activity. The processes involved here are not clear, but some method of fractionation is evidently present.

Analyses of recent sands off the South African coast by Fuller (1961 and 1962) showed a similar bimodal distribution, with grains near 2 ϕ ($\frac{1}{4}$ mm) at a minimum. Samples were collected mainly from the beach and near-shore regions, and similar characteristics were noticed down to a depth of 15 fathoms. Fuller showed that the bimodal nature of the sands was not due to lack of suitable material in the source rocks, to errors in the sieve, to mineralogy, or to a differential abrasion rate. He also proposed two methods summarized below, by which such fractionation could be achieved.

(1) By removal of the 2 ϕ fraction, due to its greater susceptibility to erosion (compared with other sand grades). This is considered doubtful, although Hjulström's curve does show a broad minimum at about 2 ϕ, indicating that this grade is easiest to erode.

(2) By a two-stage fractionation process which first concentrated the component on the beach, and then removed it by on-shore wind action.

Primary fractionation would be achieved in the swash zone where material coarser than, and including the 2 ϕ grade, would remain on the beach while finer sands returned with the backwash. Secondary fractionation would occur when the finer beach component (i.e. around 2 ϕ) was carried inland by onshore wind action. Subsequent redistribution of the depleted beach material, on the shallow sea floor during storms, would thus result in a bimodal size distribution.

Seeing that the wind is important in the above process it is significant to note that the South African samples came from shallow coastal seas subjected to strong prevailing onshore winds. Furthermore, sand of the 2 ϕ grade was found to be characteristic of the associated beaches and nearby dunes.

The close similarity between some of the current analyses and those described by Fuller is striking. The presence of the coarse fraction in a sub-horizontal layer being intimately mixed with, and then overlain by the predominant fine fraction is probably best explained by Fuller's two stage fractionation process. It may also be significant that the nearby beach and dune sands are predominantly of medium sand grade (Whincup 1944). Work on Egyptian dune sands (Harris 1957) has similarly shown the progressive sorting and downwind concentration of this component derived from initially available material in the 0-4 ϕ range. Tanner (1964) has criticized Fuller's interpretation but, nevertheless, states that such sediments may characterize nearshore marine sands.

It must be stressed that further sample analysis and theoretical clarification of Fuller's hypothesis is required before we can be sure of the exact processes involved. Sufficient analyses have however been done to indicate that the Mt Martha Sand Beds are marine, near-shore deposits. Thus they represent the early stages of the Tertiary transgression in the Mornington District.

AGE: The age of these beds is pre-Balcombian, but the absence of fossils prevents a more precise determination. Seeing that the earliest dated marine beds in the Manyung Rocks area are Batesfordian, it is probable that these sands are of approximately equivalent age.

TABLE 1

Representative Grain Size Parameters

Sample	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I
Mt Martha Sand Beds						
18(c)	2·51	0·23	+0·17	0·8	2·49	0·25
19(b)1	2·67	0·37	+0·05	1·0	2·66	0·40
21(b)	1·64	2·07	−0·05	—	1·67	—
2(d)	1·91	0·21	+0·10	1·5	1·90	0·26

HARMON ROCKS SAND BED

The Harmon Rocks Sand Bed is a layer of very coarse sand which uniformly overlies the Mt Martha Sand Beds, and underlies the Balcombe Clay. Bed (f) of Section 18 (Cranbourne, 1 mile, 071839) best illustrates this unit, the name being derived from a small point in Balcombe Bay (Locality 19).

The Bed may be traced S. of Fossil Beach Fault as beds 18(f), 19(c), 21(d) and 22(b), beyond which it dips below sea level and is probably faulted against Chechingurk Fault. In the Fossil Beach bore, it is recorded as underlying the Balcombe Clay, bed 17(f) in part, but its inland extent is unknown. The thickness of the Bed varies from 2 ft in Section 21 to 9 ft in Section 18.

The Harmon Rocks Sand Bed is composed essentially of a very coarse quartz sand (35-50%) with lesser amounts of finer sands, and some silt and clay (8-15%). Grain size analyses are shown in Fig. 10 A and B. Rare lenses of mud may be present, but much of this finer fraction is probably derived by leaching from the overlying unit. The lower junction is usually sharp and even, whereas the upper boundary may consist of a thin (2″-3″) laminated layer of mud pellets and coarse clayey sand. Internal bedding within the unit could not be discerned.

Irregular cementation by a yellow 'jarosite' mineral (refer to the section on Balcombe Clay) occurs near the top of the unit, and is prominent towards the N. end of its exposure. The colour is usually grey, except where ferruginized or cemented by 'jarosite'.

The sand fraction consists of clear quartz with only small amounts of reef quartz and weathered felspar. Rare granules and small pebbles of Palaeozoic sandstone and shale also occur. The quartz grains are subrounded and polished, but contain re-entrants indicating only a short period of abrasion (cf. roundness of underlying sands). Some of the grains in the finer 1-3 ϕ fractions are well rounded and frosted. These were probably derived by erosion of the exposed portions of

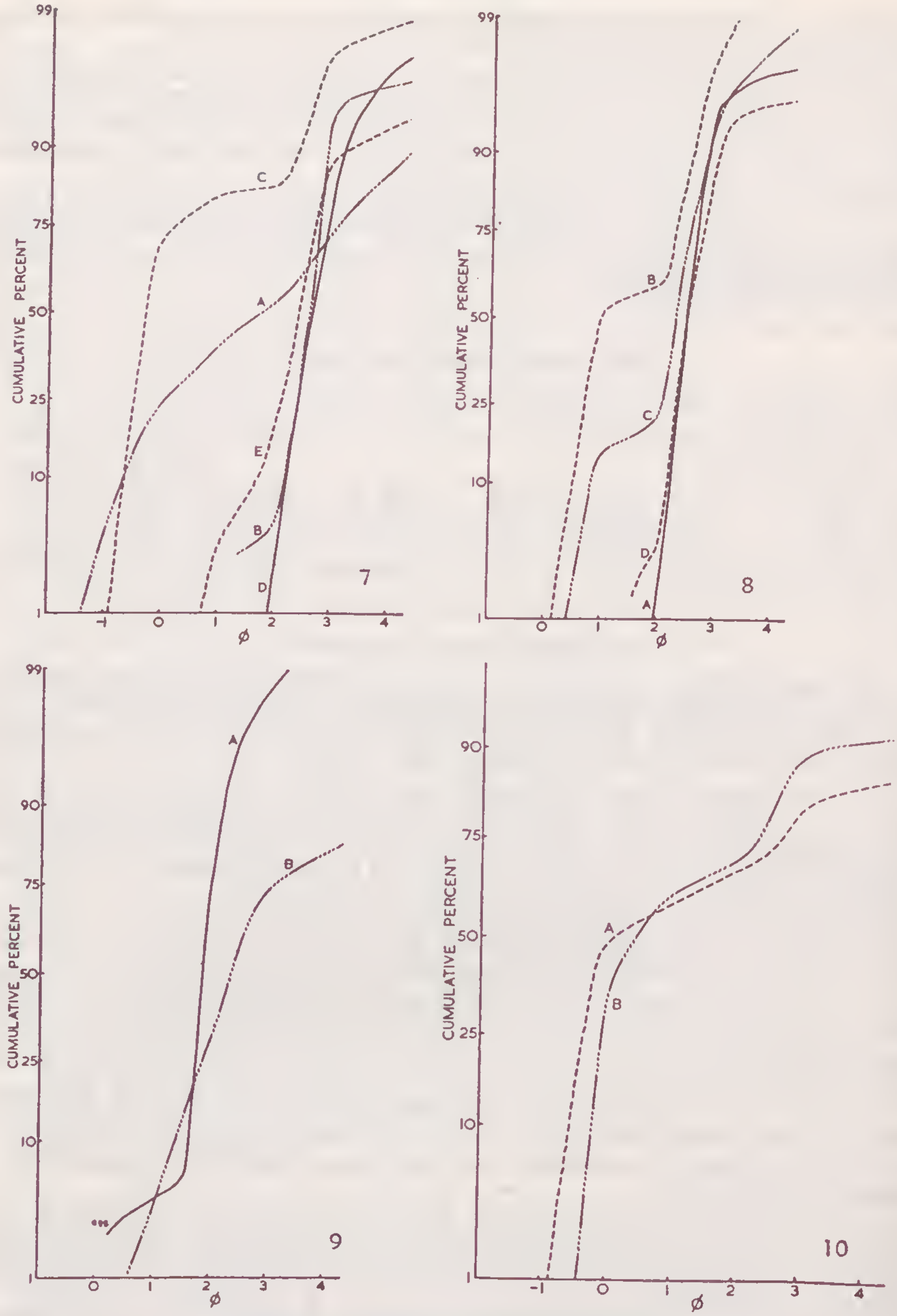


FIG. 7-10—Grain size distribution graphs.

Key:

FIG. 7—Graph A—bed 21(b); B—bed 18(a); C—Bed 18(b); D—bed 19(b) 1; E—bed 19(b) 2.

FIG. 8—Graph A—bed 18(c), 5′ below 18(d); B—bed 18(d); C—bed 18(e), 1′ above 18(d); D—bed 18(e), 7′ above 18(d).

FIG. 9—Graph A—bed 2(d); B—Pleistocene dune sand, Woolston Drive, 1½ mile S. of Frankston.

FIG. 10—Graph A—bed 18(f); B—bed 19(c).

the underlying sands. Heavy minerals consist of abundant ilmenite, with some tourmaline, rutile and zircon.

Carbonate is absent and no fossils have been found. The presence of 'jarosite' indicates that pyrite was probably present. However, the acid conditions formed by oxidation of the sulphide would have removed any initial carbonate.

ORIGIN: The coarse, poorly sorted nature of this deposit suggests a fluviatile origin. A return to such conditions may have followed a slight retreat of the sea. However, with active inland erosion possibly aided by faulting, fluviatile conditions may have re-asserted themselves without a fall in sea level. A similar influx of coarse sands persisted during the deposition of the NE. Balcombe Clay equivalent —the Sherwood Marl, at the basin margin, some 15 miles E. of Frankston (Jenkin 1962, Fig. 3).

The age of the Harmon Rocks Sand Bed is pre-Balcombian, and probably Batesfordian.

BALCOMBE CLAY

This formation is named after the well known and richly fossiliferous outcrop at Balcombe Bay, the exact locality being at Fossil Beach, 1½ mile S. of Mornington (measured Section 17; Cranbourne, 1 mile, 072845). Here, Singleton defined the Balcombian Stage of the Victorian Tertiary sequence, and gave a measured section (Singleton 1941, p. 25). Beds 17(g) to (q) (i.e. beds (g) to (k) of Singleton), are here proposed as the type section of the Balcombe Clay. This formation includes all marine silts, clays, and concretionary limestones, in the Mornington District, that overlie the Harmon Rocks Sand Bed and similar marine sands, and underlie the Marina Cove Sand. Although the predominant lithology is a clayey silt, the popular term 'clay' is used in the formational name. Use of the term 'marl' is avoided seeing that this term should strictly be applied to clay-carbonate and not silt-carbonate mixtures (Pettijohn 1957, p. 410).

EXTENT AND THICKNESS

S. of Fossil Beach (Sections 18 to 22), the Balcombe Clay is 5 to 15 ft thick and overlies the Harmon Rocks Sand Bed. At Fossil Beach it is about 70 ft thick and extends northward where it underlies Mornington. S. of Manyung Rocks (Section 10) a total thickness of about 170 ft was recorded, whereas farther N. its thickness is unknown, but it occurs in Grices, Dennant, and Ballar Creeks. Proposed leached or ferruginous equivalents occur in two outcrops at Daveys Bay (Localities 4 and 5), and in a fault remnant at Landslip Point (Section 2). The ferruginous and fossiliferous outcrop near Baxter, initially described by Chapman (1921), is also considered to be an equivalent of this formation. Inland bores have recorded possible extensions of the Balcombe Clay, but strict identification is impossible without careful sample analysis.

On the E. side of Mornington Peninsula, bores record the equivalent formation, Sherwood Marl (Jenkin 1962, p. 14) to be 40 to 130 ft thick at Tyabb. Farther E. on French I. it reaches 185 ft in thickness.

In the Sorrento Bores of the Nepean Peninsula, a similar facies of consolidated 'marl' and 'sandy marl' extends from about 900 ft down to the bore limit of 2,017 ft (Chapman 1928; Keble 1950, p. 37; and Boring Records 1955-56). It also occurs in the Rye Bores (Wannaeue 12, 13), but is much more sandy due to the influence of the nearby granitic landmass (Dromana granite).

LITHOLOGY AND INTERNAL STRUCTURE

The lithology of the Balcombe Clay is best considered under two headings:

A. The calcareous, fossiliferous, non-leached part.

B. The non-calcareous, poorly fossiliferous, leached part.

A. The Calcareous Balcombe Clay

The calcareous part is exposed at Fossil Beach, S. of Manyung Rocks, and in Grices, Dennant, and Ballar Creeks. The first three localities offer the best exposures and provide most of the detailed information. The sediment is a grey, fossiliferous, clayey silt with layers of hard carbonate concretions. The silt is sticky when wet, but shrinks and becomes hard when dried. Repeated wetting and drying, as on the foreshore exposures, causes its rapid disintegration.

Bedding or stratification within the Balcombe Clay is restricted to the layers of concretions and an occasional darker bed containing numerous and distinct light grey burrows (referred to as a burrow-bed). The size of these burrows varies from $\frac{1}{16}$" to $\frac{3}{4}$" in diameter and they were apparently made by burrowing molluscs as well as worms. Most of the sediment is indistinctly mottled in structure, with segregations or pellets of darker clay in a homogeneous silt-clay matrix. Lighter-coloured, coarser and more fossiliferous segregations, with indistinct boundaries, are also present.

At Fossil Beach, the exposure reveals a homogeneous dark grey clayey silt with a few indistinct lighter coloured segregations of silt and fossils. In the Manyung Rocks area to the north, the exposed beds are generally lighter in colour, appear to contain less clay and show more pronounced mottling. In this area the beds low in the sequence are of an intermediate nature. When very fresh, the Balcombe Clay is bluish-grey in colour but exposed sections take on an olive or yellow tint due to the oxidation of pyrite.

Grain size analyses were carried out on washed, but otherwise untreated samples, and the results are shown in Fig. 11, 13. The results are very similar and show the preponderance of silt-size particles. Median diameters vary from 5 to 7·5 ϕ and the sediment may be generally classed as a clayey silt (Shepard 1954) or of type IIIb (Inman & Chamberlain 1955). The sample from Fossil Beach is slightly finer than those from the Manyung Rocks area to the north, where there is also a coarsening toward the top of the sequence.

An estimate of the carbonate percentage was obtained by treatment with warm IM/HCl. The result of 11 analyses show the average carbonate content to be about 27%, and to vary from 11 to 43% depending largely on the amount of calcareous fossils present. Some carbonate also occurs in the finer silt and clay fractions. Samples from Fossil Beach, Dennant Ck, and from the base of the sequence S. of Manyung Rocks are generally low in carbonate as compared with the upper part of the Balcombe Clay in the Manyung Rocks area. A few sample residues were treated with disaggregating agents, and sieved through the 63 μ sieve in order to obtain sand/silt-clay ratios. However, the large proportion of non-detrital clay pellets and other mineral segregations, in the sand fraction, discouraged any further analyses.

Microscopic study of the total sand fraction revealed an abundance of fossil debris, mainly Foraminifera, but also small Mollusca and larger fossils. Mud and glauconite pellets, aggregates of pyrite and pyritic worm tubes, siliceous sponge spicules, bleached mica flakes, and quartz grains also occur in varying proportions. The amount of sponge spicules varies greatly throughout the beds. Analysis for organic carbon was not made but some appears to be present.

Mineral analysis of the finer fractions of the Balcombe Clay was carried out by X-ray diffraction of samples from Fossil Beach. The $< 2\ \mu$ fraction contains mainly quartz and clay minerals, with a very small amount of calcite. Kaolinite, illite, and montmorillonite occur in approximately equal proportions. The coarser 2-20 μ fraction contains quartz, some kaolinite, illite, and a little calcite.

CONCRETIONS: The friable clayey silt described above is interspersed with hard limestone concretions arranged in layers parallel to the bedding. They are flattened spheroidal in shape, vary in size from a few inches to several feet in length, and are usually 6-10" thick. Septarian structure is usually well developed in the concretions at Fossil Beach, but is rarely present in those of the Grices Ck area. The cause of this is uncertain and may lie in the greater proportion of clay at the former locality (and hence shrinkage on dehydration). Although the boundary of a concretion is usually sharp, it does not separate any internal feature from an external one. Its only apparent characteristic is that additional lime has been segregated causing it to become strongly lithified. Because the internal texture of these bodies is identical with that of the surrounding silt and because they are produced by segregation of carbonate within the matrix, they are called concretions and not nodules, using the definition of Pettijohn (1957, p. 200, 203).

Total carbonate in the concretions is about 80% (av.) but varies from 77 to 87%. X-ray analysis revealed the carbonate to be an impure calcite with 10-15 mol % of $MgCO_3$ in $CaCO_3$. Staining with titan yellow further showed the concentration of dolomitic carbonate in some foraminiferal tests. Detailed chemical analysis was not carried out on the concretions, but early analyses quoted in Keble (1917) show that the phosphate content is very small.

The firm nature of these bodies enabled the close study of the internal structure of the sediment by means of large polished and treated sections (lightly etched with acid, then stained with titan yellow). This process was found to highlight the structure and thin sections were used to supplement the analysis.

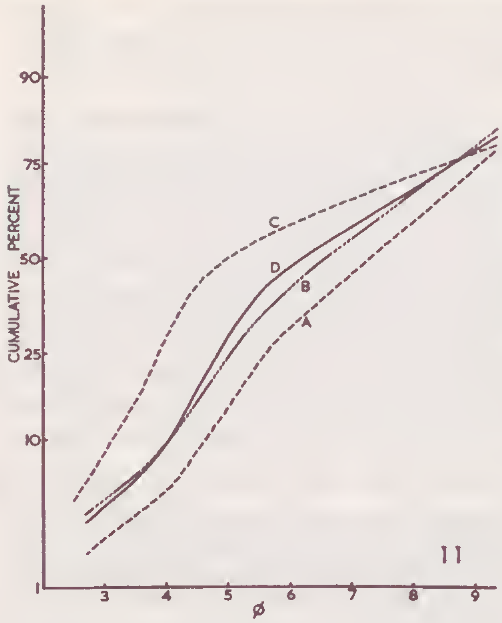
A concretion consists of fossil debris and a little quartz sand in a dark silt-clay matrix. The calcite is present in micro-crystalline form, but sparry calcite occurs infilling some fossils. Shrinkage cracks are sometimes filled with calcite crystals growing inward from the walls. Pyrite is irregularly disseminated throughout the deposit as well as partially or completely replacing some fossils. Glauconite occurs as rare light green pellets, or infills foraminiferal tests. These pellets occasionally have a centre of pyrite.

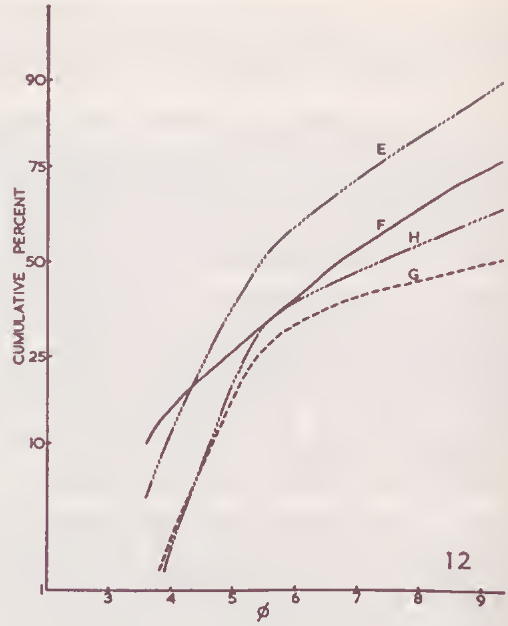
No bedding or lamination could be distinguished, the only observable structures being fine mud (? faecal) pellets and segregations of coarser silt, sand and fossils.

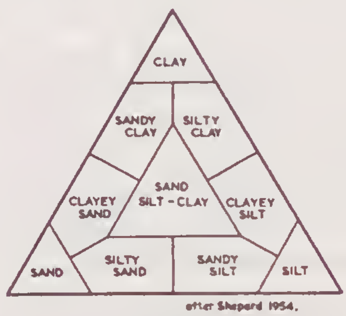
RELATION OF CONCRETIONS TO BEDDING: The concretions are found in parallel layers, and are parallel with the burrow-beds previously described. Seeing that the latter are the only definite evidence of bedding, it appears that the concretions were formed parallel to the depositional plane. In view of the mixed nature of the sediment, the preferential development of concretions parallel to the bedding direction is hard to understand. The mixing of the sediment may have been insufficient to completely homogenize the deposit, and slight difference in chemistry or porosity could have localized the precipitation of carbonate. In some horizons the concretions form an almost continuous layer, whereas in others they are only sparsely distributed. In wide exposures, such as that S. of Manyung Rocks, the layers converge and diverge slightly. Their spacing varies from 2 to 17 ft, but most of them are 3 to 8 ft apart.

B. NON-CALCAREOUS BALCOMBE CLAY

Acid solutions which accompanied the strong leaching and ferruginization of a later period, penetrated into the Balcombe Clay, removing the carbonate, and







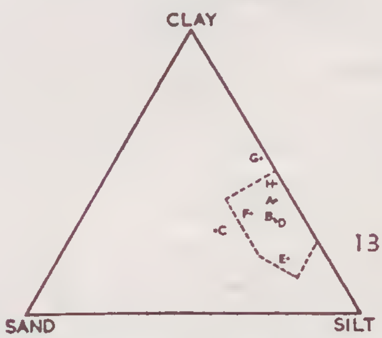


FIG. 11-13—Grain size distribution graphs of the Balcombe Clay.

Key:

FIG. 11—Graph A—bed 17(h); B—bed 10A(g), base; C—sample 10B/1; D—bed 7B(a), 30 yds upstream.

FIG. 12—Graph E—Bed 17(q); F—bed 18(g); G—bed 5(a); H—Locality 4, grey clayey silt.

FIG. 13—Locates all the above results on a sand-silt-clay diagram.

induced other mineralogic changes. Where the Balcombe Clay is thin, as in the exposure S. of Fossil Beach (e.g. beds 18(g), 22(c)) all the sediment has been affected. Where it is thick as at Fossil Beach and in the Manyung Rocks area, only the upper part has been so altered. The depth to which these changes have occurred varies from 6 ft at S. of Manyung Rocks, to some 26 ft at the N. end of Fossil Beach, and probably depended on the proximity of the surface during the period of weathering.

Its lithology is a grey to brownish-grey clayey silt similar in structure and composition to the non-leached portion, but lacking in carbonate fossils and concretions. Numerous joints usually occur and these are lined or filled with a yellow mineral. S. of Fossil Beach the base of the silt unit (e.g. bed 18(g)) is partially cemented with a similar mineral identified by X-ray diffraction and chemical analysis as karphosiderite. This is similar to jarosite (being its H_3O^+ form), and is thought to have been derived from the acid weathering of pyrite and glauconite. Reaction of pyrite with the calcareous debris in an oxidizing environment has also produced crystals of selenite at Fossil Beach.

At Locality 18, S. of Fossil Beach, opaline foraminiferal moulds have been found after careful washing of the Balcombe Clay. Siliceous sponge spicules occur sporadically and careful examination reveals that worm burrows, faecal pellets, and moulds of larger fossils are preserved in the silt where it has not been too strongly weathered or disturbed by fractures.

At Fossil Beach and S. of Manyung Rocks, a few carbonate fossils and concretions of the calcareous portion persist a short distance into the upper leached portion, but the junction of the silt is sharp, and at the former locality is also disturbed by slipping.

Grain size analyses of the non-calcareous part of the Balcombe Clay (Fig. 12, 13) show its general similarity with the calcareous part. At Fossil Beach, the non-calcareous part (graph E) has a greater proportion of sand and silt sized particles than the calcareous part (graph A). This does not of itself reflect a coarsening of the sediment seeing that the sand fraction of the former contains a large proportion of mud aggregates with lesser amounts of detrital quartz sand. Prolonged attempts at complete disaggregation failed to effect the required breakdown of the aggregates. Comparison of the grain size distribution of the two parts of the Balcombe Clay is therefore difficult except in a very general way.

Marine Sediments at Daveys Bay: Two outcrops of fine, non-calcareous marine sediments at Daveys Bay are considered to be northern extensions of the Balcombe Clay.

The first, at Locality 4, is a grey clayey silt (size anal., Fig. 12H), with yellow stained joints, similar to other exposures of the non-calcareous Balcombe Clay. Close examination reveals a homogeneous internal structure with a few faint burrows and mud pellets. Carbonate is absent, but fossil impressions occur, and washings reveal a variety of siliceous sponge spicules, Fig. 15. The sand fraction consists of these spicules with some bleached mica and fine quartz. Although the stratigraphic relationship cannot be observed, the lithology suggests the sediment to be a leached equivalent of the Balcombe Clay.

At Locality 5, the lowest bed, 5(a), is composed of indistinct layers of non-calcareous silt and clay. Because it contains marine fossils (sponges), and underlies a bed of very fine sand 5(b), similar to bed 7B(b) at Dennant Ck, it is regarded to be a leached equivalent of the Balcombe Clay. The least altered grey clayey portion of the bed was used in the grain size analysis, Fig. 12G. Results show some 55% of clay sized particles which is the highest recorded of all the samples. The sand fraction consists of limonite-replaced worm tubes and faecal pellets, siliceous sponge spicules, quartz grains, and bleached mica flakes. The limonite may be a result of oxidation of original pyrite or glauconite in the sediment.

Comparison of the size distribution of the Daveys Bay samples (Fig. 12G, H) with other Balcombe Clay samples is difficult because of the unknown quantitative effect of the acid leaching. However, both these samples show bimodal characteristics, with some 40% in the coarse silt fraction (4-6 ϕ), and the second mode in the colloid fraction ($< 1\ \mu$). This may indicate some difference in the depositional environment.

MARINE SEDIMENTS AT LANDSLIP POINT: The Landslip Point Tertiary sequence (Section 2) contains a ferruginous layer, bed 2(g), with moulds of marine fossils. It was first recorded by Kitson (1900, p. 7). Hall & Pritchard (1901) gave a short faunal list, and assumed that this outcrop was contiguous with the 'ferruginous grits which mantle the surface of the district' (i.e. the Baxter Sandstones). Chapman (1921) stressed this relationship, and by providing additional fossil determinations, attempted to date these ferruginous deposits. Singleton (1941, p. 77) criticized Chapman's dating, but continued to regard all ferruginous sediments in the district as belonging to the one formation. Keble (1950, p. 40), who regarded the fossiliferous band as representing a shallow water facies of the Miocene sea, suggested that the overlying beds may partly represent the Baxter Sandstones. However, he did not recognize the clayey silt beds 2(f) and (h) as leached equivalents of his 'Balcombian marls' (= Balcombe Clay), and stated that (p. 41): 'As the marls are not present at Landslip Point, the relationship to the fossiliferous ironstones is uncertain'.

As in the above instance, several other Tertiary ferruginous units in Victoria have been regarded as formations, e.g. the 'Moitun Creek Beds' of Gippsland. However, recent work by Wilkins (1962) in that area has clearly shown that this ferruginous unit is not sedimentary, but is a result of post-depositional weathering. In other words, the ferruginous nature is not a property of a single formation, but of all suitable formations which happen to be exposed to the influence of leaching and ferruginization.

Careful examination of the Landslip Point sequence shows that bed 2(d) overlies early Tertiary fluviatile deposits, and consists of rounded and very well sorted sands (Fig. 9A). It is probably of littoral or nearshore origin and is overlain by poorly sorted clayey sand and clayey silt, beds 2(e) to (h), probably representing a deeper water environment. The silt contains impressions of Mollusca and does not show lamination. Its total thickness is unknown because the present upper junction is landslipped. Near the base of the silt unit is a thin irregular layer of hard ferruginous silt or 'ironstone', bed 2(g), containing moulds of fossils, scattered throughout or segregated into locally rich pockets. A few yards to the north, the ferruginization affects the underlying clayey sand instead of the silt. It is important to note that the texture of the 'ironstone' is similar to that of the surrounding material, and in both cases is different from lithified samples of younger formations (Marina Cove Sand and Baxter Sandstones). The type and planar arrangement of the fossils in the Marina Cove Sand is also distinct from the Landslip Point ironstone. Furthermore, the abundant exposures of coarse poorly sorted sands of the Baxter Sandstones have not yielded any marine fossils.

From the above observations it becomes apparent that ferruginization at Frankston, as in Gippsland, has been a post-depositional, weathering effect. Thus, considering the sequence without the effect of leaching, the clayey silt unit as well as the ferruginous layer, must be regarded as being initially a calcareous clayey silt.

Because of the similarity of this sequence to other Tertiary sequences in the Mornington District (e.g. Section 10), beds 2(f) to (h) are considered to represent the Balcombe Clay at this locality.

The fauna from bed 2(g) has been listed in Chapman (1921). All the available specimens, nevertheless, have been re-examined, and those species considered to be distinctive have been listed in Table 3. From comparison with other exposures of the Balcombe Clay, it appears that this fauna shows greatest affinity with that of Fossil Beach. However, because Batesfordian-Balcombian macrofossils have not been distinguished in this study, the Landslip Point fauna is probably of Batesfordian to lower Balcombian age.

Other Balcombe Clay Equivalents: Ferruginous, fossiliferous silts (ironstones) similar to that of Landslip Point are found elsewhere in the Mornington District:

(1) An exposure of a fossiliferous ironstone in Watsons Ck (Cranbourne, 1 mile, 213892) was initially described by Chapman (1921) who identified *Chlamys praecursor*. Miss I. Crespin (in Keble 1950, p. 40) confirmed this identification and further identified *Lepidocyclina howchini* Chapman & Crespin. The former fossil has a long time range, whereas the latter is subject to facies control so that the exact age of this sediment remains unknown. Close examination of samples collected from this locality did not provide any further determinations, but showed that the texture of the matrix and the scattered nature of the fossil debris (now moulds) is similar to the ironstone from Landslip Point. Lack of exposures prevented further elucidation of the stratigraphy of this area.

(2) A specimen of a fossiliferous ironstone was found in a landslip on the N. side of Grices Ck, near the upstream section of the Balcombe Clay sequence. The texture indicates its origin to be a leached and ferruginous part of the Balcombe Clay.

(3) Some 6½ miles NE. of Frankston (Cranbourne, 1 mile, 267011), a small outcrop of Tertiary fossiliferous and ferruginous silt was recorded by Kitson (1902). Samples from this locality were later collected by A. A. Baker. Examination of these revealed a fauna of large Foraminifera (Amphisteginae), solitary corals, and small molluscs, all present as moulds. The texture of the material is similar to the Landslip Point ironstone, but is much more porous, indicating a greater proportion of calcareous debris in the original silt or 'marl'.

These exposures are considered to be of similar origin to the Landslip Point ironstone, being leached and ferruginous equivalents of the Balcombe Clay, or an equivalent formation.

Provenance and the Environment of Deposition of the Balcombe Clay

The lithology and mineralogy of the calcareous Balcombe Clay provides a good indication of the source material, the environment of deposition, the influence of the biogenic component, and the subsequent diagenesis.

Quartz, mica, and the clay minerals are all allogenic components, and have been derived from the weathering products of a variety of rocks such as granite, basalt, and older sedimentary rocks. However, some illite may have been formed diagenetically (several references given in Carroll & Starkey 1960).

The carbonate occurs mainly in the form of fossils, which, judging by their splendid state of preservation, have not been transported for any considerable distance. However, detrital fossil debris, mainly of sand size, but present also in the finer grades, was probably derived from the normal attrition of faunal remains nearer the shoreline. The fossils show little or no sign of solution, and the occasional presence of nacreous layers shows that conditions were neutral or alkaline.

The finely crystalline, disseminated nature of the pyrite and the pyritic pseudomorphs, clearly indicate its diagenetic origin. Such pyrite implies that stagnant and reducing conditions were present only at the level of formation, i.e. below the depositional interface; and oxygenated conditions capable of supporting a flourishing benthonic fauna could have been, as in this case, simultaneously present (Moretti 1957, and Greensmith 1962). The pyrite was probably formed by biochemical activity soon after deposition of the sediment. Such biogenic pyrite is known to form even in recent sediments as described by Love & Murray (1963).

The glauconite which occurs as pellets, or infills foraminiferal tests, is probably diagenetic, although some of it may have been transported. It is known to form from a variety of minerals by marine diagenesis, generally on a shelf environment under conditions of slow deposition (Deer, Howie, & Zussman 1962).

The formation of concretions post-dates that of pyrite and glauconite and is thought to be a late stage diagenetic effect. The origin of the carbonate and the process of segregation is not very clear, but the gradual expulsion of sea water from the sediment during compaction may have provided a suitable environment for the precipitation of calcite. The high pH necessary for this to occur may have been produced by the release of ammonia, resulting from the decomposition of nitrogenous organic matter, as suggested by Weeks (1957).

Interpretation of Texture and Internal Structure

Deposits of fine grained sediments are typically laminated unless there has been—

(1) Continuous sedimentation (i.e. without the slightest interruption), or

(2) co-precipitation of silt and clay with organic matter, or

(3) post-depositional disturbance.

Continuous sedimentation (or rapid sedimentation) rarely occurs over any considerable length of time and hence is restricted to thin beds or formed under exceptional circumstances. Co-precipitation of clay and silt along with organic matter or other chemical compounds such as iron hydroxide, is possible (Boswell 1961, Ch. 11), but the extent to which this occurs in nature is uncertain. In a marine environment with a large supply of clay and fine silt particles, flocculation may give rise to a more homogeneous sediment. Laminated sediments formed by intermittent deposition may be homogenized either by a physical disturbance, especially during the thixotropic state of the mud (Boswell ibid.) or by the burrowing activity of a rich benthonic fauna.

Analysis of the Balcombe Clay shows that sedimentation was slow but without significant periods of non-deposition. Both the coarse and the fine components of the sediment can be accounted for by variable currents and an intermittent supply of detritus. Once deposited, the sediment was mixed by the benthonic fauna, but some physical disruption, including the settling of coarser debris into the mud, also occurred.

Similar internal structure to that of the Balcombe Clay has been described by several workers on recent sediments (including Moore & Scruton 1957, Van Straaten 1959), as occurring on the open shelf and in enclosed bays.

Comparison of the results of grain size analyses of the Balcombe Clay with those of recent sediments, similarly shows that the environment of deposition was in the relatively quiet water of sheltered bays, or in the open sea beyond the limit of sand deposits (Inman & Chamberlain 1955, Andel & Postma 1954).

Fauna and Stratigraphy

The Balcombe Clay is noted for its abundant marine fauna, chiefly of Mollusca, Foraminifera, and other microfossils, but including Bryozoa, sponges, corals, brachiopods, echinoids, and fish.

For purposes of stratigraphy, only the first two groups are sufficiently abundant and have been sufficiently studied to provide a suite of diagnostic fossils. The Foraminifera are treated first because they are stratigraphically better known, and sampling is relatively easy. Some molluscs (chiefly Gasteropoda), thought to be distinctive of the Balcombian and Bairnsdalian Stages, are then listed. The siliceous sponge remains of the Daveys Bay outcrops are also discussed.

A. Foraminifera:

As a basis for comparison with other fossiliferous sections of the Balcombe Clay, the thickest and most complete section was first studied in detail. This section occurs at Locality 10, S. of Manyung Rocks.

Introduction: The study was largely restricted to analysis of the stratigraphic distribution of certain planktonic Foraminifera said to be diagnostic of the Batesfordian, Balcombian, and Bairnsdalian Stages in Victorian Tertiary stratigraphy (Carter 1958, 1959). These Foraminifera belong to the evolutionary sequence of *Orbulina* and *Biorbulina* (bioseries I and II, Blow 1956). The distribution of two other forms, namely *Globigerina ciperoensis* and *Globigerinoides rubra* was also noted.

It must be pointed out that, hitherto, the study of this time interval has been hampered either by lack of a complete section or by changes in environment within a section as indicated by the facies. At this locality, however, deposition has been continuous from probable middle Batesfordian to probable late Bairnsdalian time. Deposition was also confined to a single litho-facies of clayey silts. Sampling was carried out directly from the exposed shore platform, or by auger through a thin cover of beach sand. The position of the samples is accurately recorded in the description of Section 10.

Sample Analysis: Throughout this paper the concepts of species used are those of Blow (1956). The ranges of the significant fossils and the resulting subdivisions into Faunal Units are those of Carter (1959). All the samples analysed are arranged in stratigraphic order and positioned to scale on Table 2. Figure 14 is likewise drawn to scale and summarizes the information available on the evolutionary sequence proposed by Blow (1956), in relation to the section under discussion.

Sample 4: This is the lowermost fossiliferous (calcareous) sample obtained at Section 10A. The presence of *Globigerinoides bispherica, G. rubra, Globigerina ciperoensis*, and the absence of *Astrononion centroplax*, indicate that the fauna is older than F.U. 10, younger than F.U. 7, and probably younger than F.U. 8. Thus, it appears to be F.U. 9 (Batesfordian).

Samples 6, 7, 8: These all have the same fauna as the lowermost sample, but *G. ciperoensis* has not been found in them. *Globigerinoides glomerosa* and *G. transitoria* are both absent. One specimen of *G. bispherica* found in Sample 8 is almost *G. transitoria*. All these samples thus appear to belong to F.U. 9.

Sample 9: This sample is apparently only 10 ft higher in the sequence, yet the fauna recorded include abundant specimens of *G. transitoria* and many specimens of *G. glomerosa* and *Orbulina suturalis*. It is interesting to note that the entry of these forms is highlighted by their abundance and may indicate a rapid population increase following the species' evolution out of the *G. bispherica* stock. The boundary between F.U. 9 and 10 is thus taken to lie somewhere between this and the preceding sample.

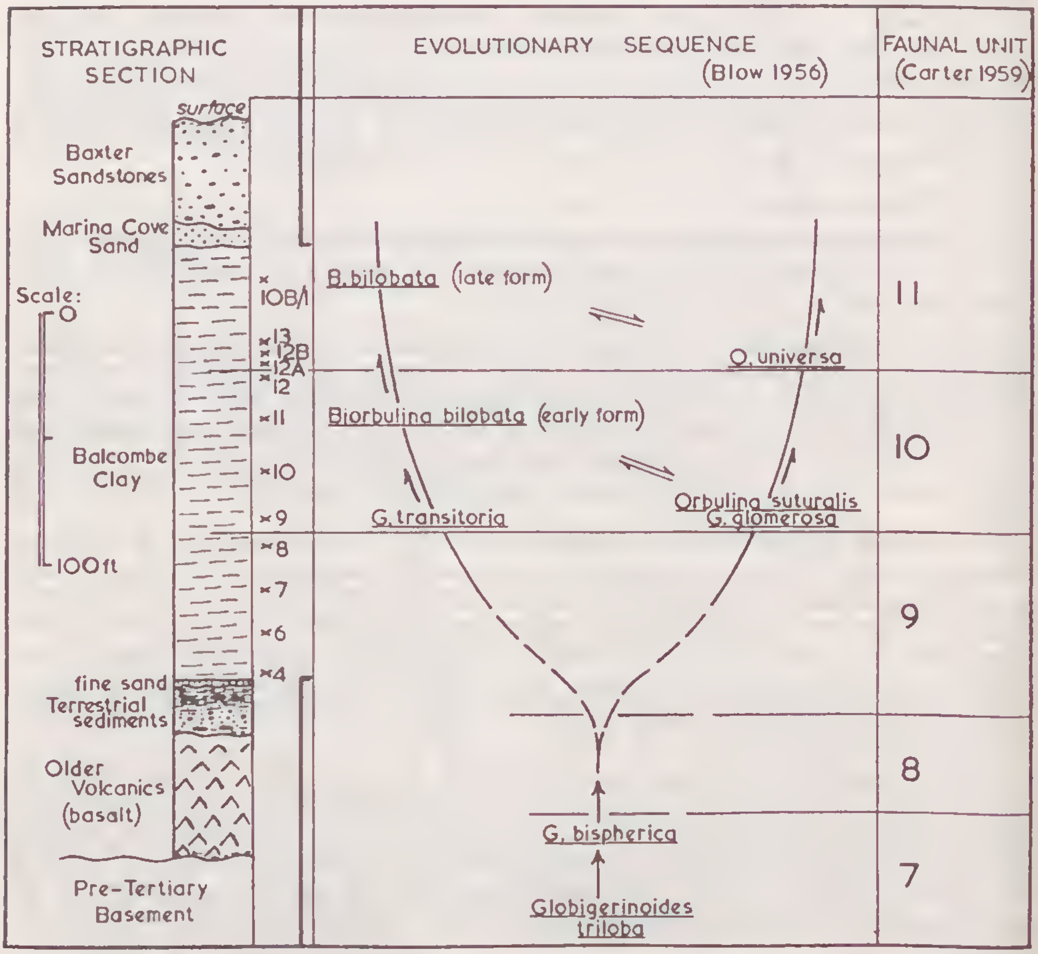


FIG. 14—Stratigraphic section at S. of Manyung Rocks. The evolutionary sequence proposed by Blow is drawn in relation to the Balcombe Clay section. Location of foraminiferal samples are shown by crosses.

Sample 10: This has a fauna similar to that of Sample 9, but no *G. transitoria* has been found in it, and only one specimen of *O. suturalis* occurs. The cause for this lack of specimens is not fully understood but an analogous situation occurs at Fossil Beach where *G. transitoria* and *G. glomerosa* occur, but *O. suturalis* is absent.

Sample 11: This sample contains *G. transitoria* and abundant *O. suturalis. Biorbulina bilobata* is rare and belongs to the early form as figured by Blow (ibid. p. 68). This is the equivalent form to *O. suturalis* in the other bioseries, but the situation is complex as indicated by the cross-over lines on the evolutionary diagram (see discussion).

TABLE 2

Foraminifera: Sample Analysis

Sample number	*Globigerina ciperoensis*	*Globigerinoides rubra*	*Globigerinoides triloba*	*Globigerinoides bispherica*	*Globigerinoides glomerosa*	*Globigerinoides transitoria*	*Orbulina suturalis*	*Biorbulina bilobata*; early form	*Orbulina universa*	*Biorbulina bilobata*; late form	Faunal Unit (Carter)
10B/1		/	/	/	/	/	X		X	/	11
13			X	X	/	X	X		X	X	
12B				X			X	/	X		
12A		/				X	X	X	/		
12				X	X	X	X	/			10
11			X	X		X	X	/			
10		/	/	X	X		/				
9			X	X	X	X	X				
8		/	X	X							9
7		X	X	X							
6		X		X							
4	X	X	X	X							

Sample 12: *O. suturalis* occurs in abundance and includes many specimens whose ultimate chamber envelops more of the preceding chambers than was seen in specimens from Sample 11. The early form of *B. bilobata* also occurs, along with *G. glomerosa circularis*. This sample is still typical of F.U. 10.

Sample 12A: This sample was taken only 11 ft away from the previous sample. This is only 6 ft higher in the sequence due to the dip on the beds. Species found are those listed in the table. Especially noteworthy is the first appearance of a few specimens of *O. universa* (thick and thin shelled forms).

It is very difficult here to distinguish *O. suturalis* from *O. universa*, seeing that the ultimate chamber of the *suturalis*-form almost completely covers the previous chamber. In fact, these early chambers are only visible by outline of the sutural pores. The above change in the form of *O. suturalis* occurs gradually and is characteristic of the evolution of this form.

This horizon then, marks the beginning of F.U. 11 (Bairnsdalian). Many arenaceous Foraminifera are also present here.

Sample 12B: This is another 5 ft higher in the sequence and has *O. universa* in abundance. *B. bilobata* is still the early form.

Sample 13 and the Sample 10B/1 (near the top of this sequence) contain an abundance of *O. universa. O. suturalis* still occurs, and *B. bilobata* is here the late form. After F.U. 11, planktonic Foraminifera are not abundant and, therefore, the uppermost sample is probably still Bairnsdalian.

Discussion: Although these studies have been somewhat limited in scope, the results, nevertheless, are consistent with the scheme of evolution as outlined by Blow.

Development of the equivalent forms in the two bioseries appears to have taken place in a parallel manner, although the entry of *Globigerinoides glomerosa* relative to that of *Orbulina suturalis* is uncertain. Further work with closer sampling should show the complete evolutionary sequence. Nevertheless, it became apparent from this study that there is an intermingling of forms making it very hard taxonomically to differentiate any of these species. The work of Belford (1962) has further emphasized this difficulty. Belford studied the formation of *O. universa* and of *Biorbulina bilobata*. His thin sections reveal that certain thick shelled forms of *Orbulina universa* would be classified as *O. suturalis* after the formation of the initial globular chamber, and that it is the addition of subsequent layers to this shell that obscures and then completely covers the trace of the earlier chambers. Certain forms, however, are said to be of the *universa*-type throughout.

Belford thus points out that *O. universa* may be either a true *O. universa* or an *O. suturalis* which has had subsequent external layers added to it. However, in areas such as Trinidad and New Zealand, *O. suturalis* is known to occur well before any *O. universa* (Belford 1962, p. 6). This is also seen in the present study and, thus, it is felt that this overgrowth occurs only in the very late forms of *O. suturalis*, those in which the earlier chambers are almost completely covered up by the final chamber. This overgrowth stage probably occurs contemporaneously with the entry of true *O. universa*, as may be observed in Sample 12A where apparently thin and thick-shelled *O. universa* forms occur. Certainly the next overlying sample (only 5 ft up) has many true *universa*-types.

Belford does not give orders of appearance because his samples lack stratigraphic continuity. He has not studied a complete section which demonstrates the morphotypic sequence outlined by Blow and, furthermore, all his samples appear to have come from the highest Faunal Unit here described (F.U. 11). Seeing that the entry of both true and 'obscured' *universa*-types appears to be contemporaneous in this section, the entry of either type is held to mark the base of F.U. 11 (Bairnsdalian). This is a tentative state of affairs and awaits further clarification.

The second bioseries of Blow, involving *Biorbulina bilobata*, is more difficult to study due to the relative lack of specimens. In all, about a dozen specimens of this form were found in samples from this section. The lack of specimens may have led Carter (1959) to restrict the entry of *B. bilobata* to F.U. 11 but, as is clear from the faunal list, *B. bilobata* (early form) is present along with *O. suturalis* and well before *O. universa*. Blow (1956, p. 60), however, states that *B. bilobata* appears before either *O. suturalis* or *O. universa*. Belford (1962, p. 8) says that bilobate forms develop only from thick-walled single-chambered specimens of both *suturalis* or *universa*-type. This cannot be so if the above statement by Blow is correct. From the sections illustrated by Belford, however, it does appear that bilobate forms do sometimes develop from single-chambered forms. In the present study, one specimen of a bilobate form was found with the second chamber markedly thinner than the previous chamber indicating this addition. Also recorded were some forms which have a smaller thin additional chamber added to the standard form (e.g. *G. bispherica*). This chamber varies widely in size and is usually spheroidal. Sometimes it is oblate or irregular, and it appears only on the thick-shelled forms. It probably enabled the individual to retain buoyancy as suggested by Belford.

CONCLUSION: It thus appears from the work of Blow and Belford that *O. universa* evolved from *G. bispherica*, and that there are morphotypic variants between these two species. These morphotypes can be recognized, appear to occur in a definite time sequence and, therefore, are of stratigraphic significance in the section described. Carter's Faunal Units 9, 10, and 11 are based on this evolutionary sequence, and the establishment of these Faunal Units is thus clearly justified.

MICROFAUNA IN OTHER SECTIONS:

Fossil Beach—

A large list of Foraminifera found at Fossil Beach, as well as at other nearby areas, was published in three parts (Chapman 1907a, Chapman & Parr 1926, Chapman & Collins 1934). Carter (1959) records certain critical forms found here, but only deals with the surface samples. Core-samples obtained from the basal 7 ft of the Balcombe Clay, bed 17(g), came from Bore 6, Moorooduc, and were kindly lent for study by the Victorian Mines Department. Of the diagnostic species, only *G. bispherica* and a couple of specimens of *G. transitoria* were found. Furthermore, many forms of *G. bispherica* are intermediate between itself and *G. transitoria*. In terms of Carter's Faunal Units this appears to indicate that the base of the Balcombian type section is indeed very low in F.U. 10.

The surface sample, as recorded by Carter (ibid.), contains *G. transitoria* and *G. glomerosa curva*, but '*O. suturalis* has not been found at Balcombe Bay'. In the present study the writer has tried to find this form by taking as stratigraphically high a sample as possible in the calcareous interval. *G. transitoria* and *G. bispherica* are the only significant forms that occur and no *O. suturalis* was found. As there is still some 20 ft of overlying leached silt, it is likely that *O. suturalis* may be present in this interval. However, there may be other reasons for its apparent absence. Nevertheless, it is significant to note that, although the type section of the Balcombian Stage (Singleton 1941) includes this leached interval, Carter's definition of F.U. 10 does not, and is only partly based on forms in the underlying calcareous beds. Because of this anomaly (which applies similarly to the macrofauna), it may be advisable to redefine the Balcombian Stage so as to exclude this leached interval. In this paper, however, the Balcombian Stage is taken to be synonymous with Faunal Unit 10 as defined by Carter.

Foraminifera have also been found in the non-calcareous claycy silt, on the upthrown side of the fault, S. of Fossil Beach [bed 18(g)]. Washings of this silt reveal opaline moulds of Foraminifera making accurate determination of species impossible. This is especially so with regard to *Orbulina* sp. which appears to be present along with other Globigerinidae.

Grices Ck—

Upstream Section (8A): A sample obtained from the base of this section contained the following forms: *O. suturalis, B. bilobata, G. transitoria,* and *G. bispherica*. Another sample from within a few feet of the top of this section contained: *O. suturalis, B. bilobata* (early form, Blow), *G. transitoria,* and *G. bispherica*. Thus all this section is Balcombian (F.U. 10) in age.

Downstream Section (8B): A sample obtained from the base of this section contained: *O. universa* which was not abundant, *O. suturalis* (abundant), *G. glomerosa* (?), and *G. bisperica*. Thus, it is of probable early Bairnsdalian (F.U. 11) age.

A further sample was taken at sea level, just N. of the Ansett pier, about 200 yds S. along the coast from Grices Ck. It contained *O. suturalis, B. bilobata, G. transitoria,* and various forms of *G. glomerosa*. These indicate a Balcombian (F.U. 10) age.

The presence of Balcombian strata along this part of the coast explains the hitherto puzzling presence of 'Fossil Beach-type' macrofossils in old collections from this area.

Dennant Ck—

Upstream Section (7A): A sample obtained from this locality contained *G. transitoria* and *G. bispherica*. No *O. suturalis* could be found, hence the strata at this locality are early Balcombian (F.U. 10) in age.

Downstream Section (7B): A sample from the calcareous silt at this locality contained *O. suturalis* and *G. bispherica*, indicating a Balcombian (F.U. 10) age. Seeing that this exposure is some 30 yds upstream from the rest of the measured section (7B), *O. universa*, indicating a Bairnsdalian (F.U. 11) age, may be present in this covered interval.

B. Diagnostic Mollusca:

Having established the stage chronology of the outcrops according to the Foraminifera, it remained to be seen how far the Mollusca could be used for stage identification.

Because the proved Batesfordian outcrop is restricted in exposure (base of Section 10A), the macrofauna obtained from it is insufficient as yet in quantity to be of stratigraphic use. Hence, only the Balcombian and Bairnsdalian Mollusca are compared. It must be noted that the large faunal list of Hall & Pritchard (1901) is accurate for the Fossil Beach outcrop (Balcombian), but the list for Grices Ck contains a mixed Bairnsdalian-Balcombian assemblage.

The material used was that collected during the current field work, supplemented by other collections, only where the specific locality had been noted. These collections were those of T. A. Darragh (pers.), and of Cudmore (Nat. Mus. Vict.). The Mollusca were determined by T. A. Darragh (Geology Dept, University of Melbourne).

Only some of the common and distinctive forms are shown in Table 3. The six major localities are arranged in stratigraphic order from right to left, based on foraminiferal studies and field relationships. Fossils collected from the section S. of Manyung Rocks came from bed 10B(a).

Examination of this table shows that there are a sufficient number of forms distinctive of either the Balcombian or the Bairnsdalian stages to be useful for correlation purposes.

TABLE 3
Mollusca

LOCALITY:	S. of Manyung Rocks	GRICES CREEK		DENNANT CREEK		Fossil Beach	Landslip Point
		Dnst.	Upst.	Dnst.	Upst.		
SECTION NO.	10B	8B	8A	7B	7A	17	2
Arca capulopsis (Pritchard)		lp					
Turritella aff. *T. adelaidensis* (Cotton & Woods)	X	up					
Murex lophoessus (Tate)						X	?
M. sp. nov. aff. *M. lophoessus* (Tate)	X	X					
Typhis sp. nov. aff. *T. maccoyi* (Tenison Woods)	X	X					
Columbarium foliaceum (Tate) ..				X	X	X	
C. craspedotum (Tate)					X	X	X
C. sp. nov. aff. *C. craspedotum* (Tate) *scabrose* type	X	up					
C. sp. nov. aff. *C. craspedotum* (Tate) non-*scabrose* type	r	c					
Zemira praecursoria (Tate)	X	X					
Turris septemlirata (Harris)	c	c				vr	
Micantapex decompositus (Tate) s.l. ..	X	X	up				
M. perarmatus (Powell)			X	X			
M. rhomboidalis (Tenison Woods) s.s.					X	X	X
Conus dennanti (Tate)						X	
C. ligatus (Tate)						X	
Austrovoluta antiscalaris antiscalaris (McCoy)..			?s	X	X	X	
A. antiscalaris levior (McCoy) ..	X	X					
Nannamoria absida (Cotton)	X						
Faunal Unit (Carter):	11	11	10	10	10	10	
Stage:	Bairnsdalian		Balcombian				

Key:

X = present
? = Determination uncertain
?s = specimens not *in situ*
c = common
r = rare
vr = very rare
up = upper part of section
lp = lower part of section
Upst. = upstream section
Dnst. = downstream section

C. Siliceous Sponges:

The fossils at Locality 5 (Daveys Bay) include small sponges, mostly in a single horizon near the base of bed 5(a), and scattered siliceous sponge spicules.

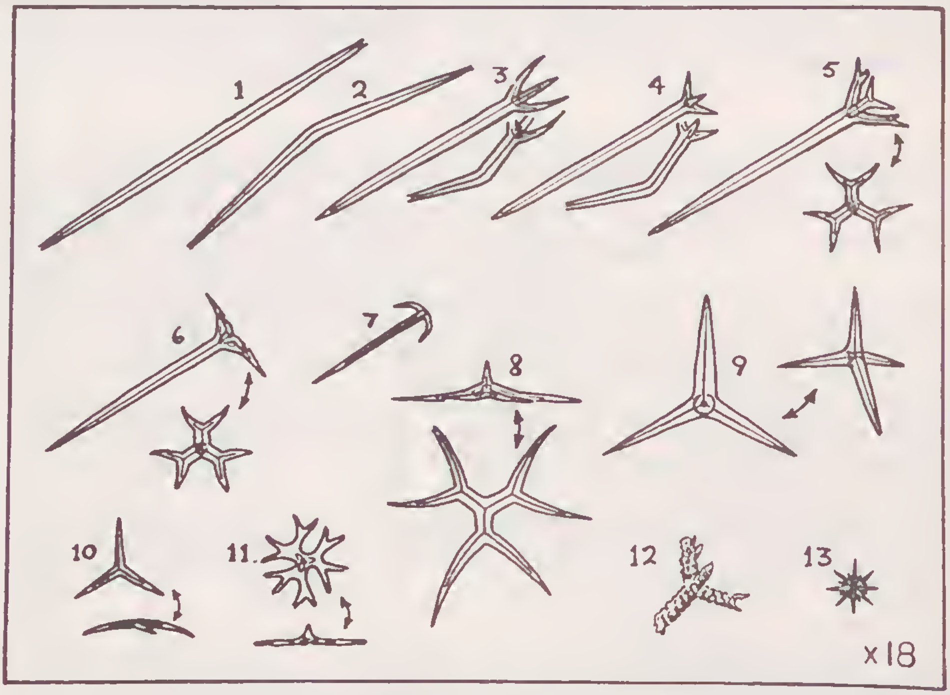


Fig. 15—Siliceous Sponge Spicules in the Balcombe Clay and probable weathered equivalents.

Type	Fig.	Sample		
		1	2	3
Oxea (fusiform)	1	X	X	X
Oxea (fusiform)	2		X	X
Protriaene	3	X	1 sp	X
Protriaene	4	X	X	X
Dichotriaene	5	X	X	X
Dichotriaene	6	X	X	X
Anatriaene	7			1 sp
Dichotriaene (with short shaft)	8	X	X	X
Calthrops	9	X	X	X
Triact (regular)	10			1 sp
Triaene (?) and similar irregular forms ..	11	X	X	X
Calthrops (?) and similar irregular forms ..	12	X	X	X
Euaster (oxyaster)	13	X		X

Sample:
1 = Dennant Ck—Section 7B, bed (a) 30 yds upstream.
2 = Daveys Bay—Locality 4.
3 = Daveys Bay—Section 5, bed (a).

Various burrows are present, but other fossils have not been found. A short note by Kitson (1900, p. 10) on the presence of lamellibranch casts in a yellow plastic clay at Wallace Bay (= Daveys Bay) probably refers to this exposure.

Several types of sponge spicules found in the Balcombe Clay at Dennant Ck are shown in Fig. 15. Comparison with spicules obtained from both the Daveys Bay outcrops, shows a clear similarity, thus providing further evidence that these outcrops represent leached parts of the Balcombe Clay.

Most spicules are fresh and do not show signs of reworking. Specific determination of the sponges was not made but some of the spicules may belong to the Tertiary sponge *Ecionema newberyi* (McCoy 1877), figured Chapman 1907b, Pl. 18. The sponges from bed 5(a) are irregular to cylindrical in shape, fragments are usually less than 1" long, with a diameter of 1/16" to 1/4". They are composed of an irregular network of clear, smooth to rough, and generally irregular type-12 spicules (see diagram). Other remains consist of bunches of oxeas and rare triaenes.

Summary of the Stratigraphy and Depositional Environment of the Balcombe Clay

Analysis of diagnostic Foraminifera has enabled Carter's Faunal Units, and hence the Tertiary Stages, to be determined for all calcareous outcrops of the Balcombe Clay. Certain Mollusca have been similarly useful in this regard, especially in the case of the non-calcareous ferruginous outcrop at Landslip Point. In other non-calcareous portions of this formation, such as at Daveys Bay, the presence of comparable siliceous sponge remains has aided in identification of the unit.

All the available data on the age of the Balcombe Clay outcrops are summarized in a Correlation Chart (Fig. 16). The outcrops are arranged in order from Frankston, S. to Fossil Beach. It is unfortunate that the precise Stage of the Landslip Point outcrop cannot be determined, as this would indicate when the deeper water facies of clayey silts began to be deposited here. The base of the Balcombe Clay has been dated only at the sections S. of Manyung Rocks and Fossil Bach. From these it is apparent that deeper water existed in the Grices Ck area concurrent with sub-littoral and fluviatile conditions at Fossil Beach. This phase was followed by a more widespread submergence during the Balcombian.

The textural, structural, and faunal studies have shown that the Balcombe Clay was deposited in relatively quiet marine waters, either on the open shelf beyond the limit of sand deposits (including calcarenites), or sheltered behind land barriers, but with access to the sea.

The extensive nature of the Balcombe Clay and equivalent formations at Geelong and Western Port (Fig. 22), the presence of calcarenites and sandy facies towards the shoreline (e.g. Bowler 1963, Fig. 13; Jenkin 1962, Fig. 3), and the lack of evidence regarding any extensive land barrier, strongly suggest that deposition of this formation was on the open shelf.

Marina Cove Sand

Although sediments of this formation have been generally regarded as forming part of the Baxter Sandstones, the characteristic lithology and widespread nature of this unit justifies its formational status.

It consists of a very well sorted, very fine sand overlying the Balcombe Clay, and underlying the poorly sorted and generally coarse sands of the Baxter Sandstones. Several good exposures of this formation are available in the Mornington District, but beds 17(r) and (s) at Fossil Beach may be taken as representative (Cranbourne, 1 mile, 072845). These are the same beds as Singleton's bed (1)

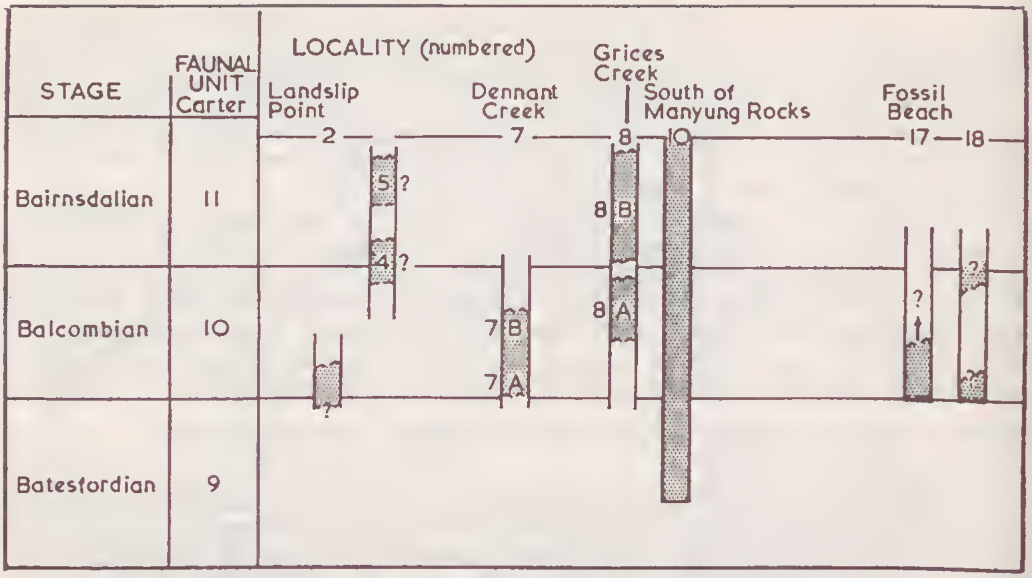


FIG. 16—Correlation chart of the Balcombe Clay in the Mornington District.

(1941, p. 27). The name is taken from a small bay, Marina Cove, situated ½ mile N. of Fossil Beach.

The Marina Cove Sand extends from near Mt Martha, bed 21(f), N. to Daveys Bay, bed 5(b). Lack of suitable exposures prevents its actual extent being known, and it has not been definitely identified in the boring records. A possible equivalent is a fossiliferous fine sand bed at Warneet, 14 miles E. of Mornington (Jenkin 1962, p. 47) which overlies the ?Sherwood Marl (equivalent to the Balcombe Clay). The Marina Cove Sand varies from 2 ft thick at Section 21, to 17 ft thick at Marina Cove, beds 15(b) and (c), and is generally 5 to 10 ft thick.

Lithology

The lithology of the Marina Cove Sand is characteristically uniform, consisting of yellow or varicoloured very fine sand. It is generally friable, but is occasionally cemented by limonite, or held firm by clay. The base of the unit sometimes contains small pellets of clay and rare grains of coarser sand, possibly indicating a slight disconformity, e.g. beds 9(e), 15(b), 17(r). The uppermost foot of the unit may also have similar characteristics. Gentle cross-bedding may be present but is difficult to distinguish from secondary limonite stains. At Manyung Rocks, bed 9(f) contains moulds of molluscs and echinoids which occur in well defined horizontal planes. The orientation of the lamellibranchs is mainly concave up. The carbonate originally present within this sediment has been removed by later acid conditions which accompanied the ferruginization.

Grain size analyses on several samples of this formation have been done, and results are shown in Fig. 17 and 18. Representative grain size parameters are found in Table 4. The proportion of silt and clay is variable, and may be as high as 33%. Usually it is about 25%. Much of it is either in the very coarse silt grade, immediately beyond the sieve limit (64 μ) or exists as mud pellets (? faecal). Some of this fraction, however, is thought to have been introduced by leaching. Such non-detrital mud, and the presence of limonitic aggregates, creates the poor sorting effect at either end of the cumulative curves. Statistical parameters, such as those using the 95th percentile, cannot be determined. For this reason the result of bed 6(b), with virtually no aggregates, has been recalculated to sand =100%, and the parameters for this are shown in Table 4.

Allowing for the presence of aggregates and mud, the results of the size analyses show the sediment to consist of a very well sorted, very fine sand (average mean $3 \cdot 7\ \phi$).

The mineralogy is predominantly quartz, but a few pale mica flakes and rare weathered felspar grains are present. Heavy minerals are mainly tourmaline, zircon, and ilmenite. Some irregular rounded grains of a goethite aggregate occur, probably formed by oxidation of glauconite pellets (which they resemble).

Most quartz grains are equant, angular to sub-rounded, but the larger grains are very angular and usually bladed or tabular in shape. The quartz may be clear or 'milky' with numerous minute inclusions. Only a few grains show strain extinction.

The source of the sediment is thus from a variety of rock types including granites, metamorphics and older sediments.

Fauna and Age

Apart from ferruginized worm burrows, fossils are rare in the Marina Cove Sand. Bed 9(f) at Manyung Rocks contains other recognizable remains including several species of lamellibranchs, some monostychiids, and rare gastropods.

Deposition of the Marina Cove Sand closely followed that of the Balcombe Clay. Thus, it is of Bairnsdalian to Mitchellian age. The restricted fauna, influenced by the environment, does not enable any more definite determinations to be made.

Environment of Deposition

The fine grade, good sorting, and the fauna indicate a marine environment of deposition. Compared with the underlying clayey silts, the deposition of the sand implies an increase in the energy of the environment which enabled the removal of the finer fraction into deeper water. The lack of coarser sands probably indicates a considerable distance from the shore, and orientation of the lamellibranchs similarly shows that conditions were by no means vigorous. The very good sorting, however, does indicate a considerable period of reworking of the sand which would have occurred in the region above wave base (probably less than 7 fathoms).

Comparison with recent sediments (Inman & Chamberlain 1955, Friedman 1962) substantiates the above conclusions. The Marina Cove Sand is rather fine for a littoral deposit, and belongs to a very well sorted Type II sediment which occurs in the shallow water shelf region (Inman & Chamberlain ibid.).

Relationship of this Formation to the Tertiary Cycle of Deposition

The marine regression which probably began during the deposition of the upper parts of the Balcombe Clay, was intensified during the deposition of the Marina Cove Sand, and reached its culmination in the fluviatile deposits of the overlying Baxter Sandstones.

Baxter Sandstones

The Baxter Sandstones have been defined by Keble (1950, p. 41) as 'the Tertiary fluviatile ferruginous sandstones' covering most of the central and northern parts of the Mornington Peninsula. A section illustrating this formation was given. It occurs in a road-cutting some distance inland from Mornington, but is unsatisfactory because its limits are undefined.

Along the coast, however, many good sections of the Baxter Sandstones are exposed, the basal limit of which can be clearly defined as the first entry of abundant coarse sand overlying the Marina Cove Sand. A typical exposure may be seen at Section 16, about ½ mile N. of Fossil Beach (Cranbourne, 1 mile, 072852), where beds 16(c) to (i) represent the Baxter Sandstones.

It is proposed to tentatively define the top of the Baxter Sandstones as the upper limit of ferruginization of these deposits. It is realized that this limit need not represent a true stratigraphic boundary, but this definition provides some type of upper limit which can be used in mapping and stratigraphic studies.

Extent and Thickness

In the Mornington District, Baxter Sandstones are widespread, and usually overlie the Marina Cove Sand. Although undisturbed exposures are lacking, it appears that part of the Baxter Sandstones is unconformable with older formations, e.g. at Section 2 (Landslip Point), Section 11, and overlying granite on the south of Section 10.

Identification of inland ferruginous sands is difficult because tectonic activity (as on the Manyung Fault) is known to have exposed early Tertiary fluviatile sediments to the effects of ferruginization. These sediments have a similar lithology to the Baxter Sandstones so that, where characteristic intervening units (e.g. the Balcombe Clay) are absent, the identity of the sands is uncertain. Thus, the ferruginous sands which overlie the Palaeozoic basement in the central and northern parts of the Mornington Peninsula may be part of the Baxter Sandstones, or may be ferruginous equivalents of considerably older strata.

Along the coast the thickness of the Baxter Sandstones is usually 40 ft but may be considerably thicker in the region between Grices Ck and Pelican Point. In this area the sequence appears to be broadly folded, possibly due to uneven displacement along the Manyung Fault. The dips on the major bedding planes are shown on Fig. 4. Between Canadian Bay and Pelican Point a general southerly dip occurs, but the dips measured are probably those of initially inclined beds, seeing that a constant dip of 10° over this interval would indicate a rather improbable thickness of 1,000 ft of Baxter Sandstones, whereas a maximum of 80 ft is expected.

Lithology

The Baxter Sandstones consist mainly of coarse, moderately to poorly sorted sands, with variable amounts of gravel, finer sands, and clay. The sands are cross-bedded in discontinuous layers but a general sequence may be discerned:

> The basal bed of the Baxter Sandstones consists of coarse to very coarse sands with some gravel, e.g. beds 15(d), 16(c), 17(t). Its lower contact gives the appearance of being scoured into the underlying unit, although post-depositional deformation may have occurred.
>
> This basal bed may be overlain by several feet of poorly sorted fine sands with cross-bedded coarse sands, e.g. beds 7B(c), 15(e), 16(d), to (f).
>
> This unit is in turn succeeded by the main thickness of coarse to very coarse sands, cross-bedded, and interbedded with clayey sands and sandy clays. The upper part of the Baxter Sandstones is usually finer in texture and overlain by buckshot gravel, e.g. beds 7B(d), 10B(d) in part, 13(b) and (c) in part, 16(g) to (i), 20(f) to (h) in part.

Good exposures of the Baxter Sandstones usually show cross-stratification with sets of cross strata from a few inches up to a foot thick. High angle (20°) planar, and trough cross-bedding is most common. Very similar cross-bedding occurs in recent fluviatile sands (e.g. Lane 1963, Harms et al. 1963). Results of grain size analyses of the Baxter Sandstones are shown in Fig. 19, 20. Representative parameters are listed in Table 4. The clay and silt fraction is usually about 10% but reaches 29% in the sample from bed 10B(d). This high proportion is thought to have been mainly derived from the weathering of felspar in the original sediment, seeing that partially weathered felspar grains are often present. Some of the analyses have been recalculated to sand =100%, and the parameters are shown in the same table. Most of the analyses were done on the less altered, coarser beds near the base of the unit, but Fig. 20A shows the result obtained from the cross-bedded coarse and fine sands overlying the lowest coarse sand horizon. Bed 22(d) is not ferruginous and it may represent fluviatile sediments younger than the Baxter Sandstones (size anal. Fig. 20C).

The mineralogy of the Baxter Sandstones is predominantly of clear quartz with minor amounts of chert and quartzite. Felspar occurs in small and variable amounts and is usually altered to clay. Much of this felspar did not withstand the strong disaggregating treatment in preparation for the size analysis, so that the silt + clay percentage has correspondingly increased. Compound grains of quartz and felspar also occur. Gas and other inclusions are common in the quartz, which rarely shows strain extinction.

Heavy minerals consist mainly of ilmenite, zircon, rutile, and tourmaline; biotite is present.

The quartz grains show varying degrees of roundness. Some are rounded, lightly frosted and pitted, whereas most are sub-rounded to sub-angular, usually clear and with fresh surfaces and re-entrants.

Flora and Age

Although a large number of exposures of the Baxter Sandstones were studied, the only fossils found were those of ferruginized wood. Several pieces and logs of wood occur on the SW. side of Fisherman Point, and at the N. end of Ranelagh Beach. A sample from the latter exposure was identified by Mr A. A. Baker (Geology Dept, University of Melbourne) as probably *Banksia* sp. (MUGD No. 3532).

Lack of suitable fossils in the Baxter Sandstones does not enable an accurate age determination to be made on these deposits. Since there does not appear to have been any widespread and intense ferruginization in Victoria after the Cheltenhamian, and seeing that these deposits are probably younger than the Bairnsdalian, it is considered that they are of Mitchellian to Cheltenhamian age.

Origin

The coarse poorly sorted texture, steep cross-bedding, and flora of the Baxter Sandstones indicate a fluviatile environment of deposition. Comparison of the size distributions with those from modern sediments also shows its similarity with river deposits (Friedman 1962).

The distinct entry of coarse sands that marks the base of this formation suggests that the shallow water marine conditions, prevailing during the deposition of the Marina Cove Sand, changed rapidly into vigorous fluviatile conditions probably as a result of inland tectonic activity. The uplifted older sediments and partially weathered granites provided the source material.

Ferruginization

The work of Wilkins (1962) on some Tertiary sediments of Gippsland has shown that the strongly ferruginous nature characterizing the 'Moitun Creek Beds' is not a sedimentary feature, but one brought about by surface leaching and 'soil'

TABLE 4

Representative Grain Size Parameters

SAMPLE	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	M_z	σ_I
Marina Cove Sand						
17(s)	3·74	0·18	+0·20	1·1	3·72	0·20
19(e)	3·71	0·17	+0·30	1·3	3·69	0·20
R. 6(b)	3·41	0·19	0·00	0·5	3·41	0·18
Baxter Sandstones						
17(t)	0·37	0·91	+0·33	—	0·26	—
7B(d)	0·36	0·78	+0·15	—	0·32	—
R.7B(d)	0·25	0·73	+0·11	0·7	0·22	0·75
R.10B(d)	−0·52	0·85	+0·19	0·6	−0·57	0·84
R.17(t)	0·21	0·72	+0·38	0·7	0·12	0·73
22(d)	2·42	0·76	−0·03	—	2·43	—
R.22(d)	2·21	0·61	−0·13	0·8	2·23	0·63

R = Recalculated to sand = 100%.

formation during the late Tertiary. Much of the Mornington Peninsula shows evidence for a similar phase of widespread leaching and ferruginization following the deposition of the Baxter Sandstones. Thus, we find weathered and ferruginous granite at Mt Eliza, and ferruginous Ordovician sediments farther inland; ferruginous basalt near Mt Martha (Locality 23), and early Tertiary sediments at Landslip Point, bed 2(c), and probably at Locality 12; ferruginous and fossiliferous Balcombe Clay equivalents at Landslip Point, bed 2(g), at Grices Ck, and at Watsons Ck (details under 'Balcombe Clay'); and the leached and ferruginous Marina Cove Sand and Baxter Sandstones.

Ferruginization within the last two units is especially conspicuous along the coastal section in the Mornington District. The acid leaching which accompanied the alteration extended down to include the upper part of the Balcombe Clay, thus removing all the carbonate.

ORIGIN

The presence of ferruginous but friable sediments in bores, and in fresh exposures (e.g. road cuttings) indicates that the process of lithification of these rocks is due to atmospheric exposure. This may be related to partial dehydration of ferric hydroxides giving a firm limonitic clay bond forming the ironstone.

The iron has been derived from the intense weathering of detrital iron bearing minerals, and especially from the iron ore minerals, although there is no evidence to suggest a greater abundance of these in the more ferruginous parts of the sediment. The ferruginization is clearly seen to cross lithological boundaries and its position has probably been controlled by the proximity of the surface of weathering. The sediments may be generally termed lateritic, but the term laterite should not be used in view of the dissimilar nature of the profile. In the Mornington District, there is no evidence to indicate any ferruginization prior to the late Tertiary, after the deposition of the Baxter Sandstones.

LATE-TERTIARY NON-FERRUGINOUS SEDIMENTS

Following the deposition of the Baxter Sandstones and the period of widespread ferruginization, the only deposits of probable Tertiary age in the Mornington

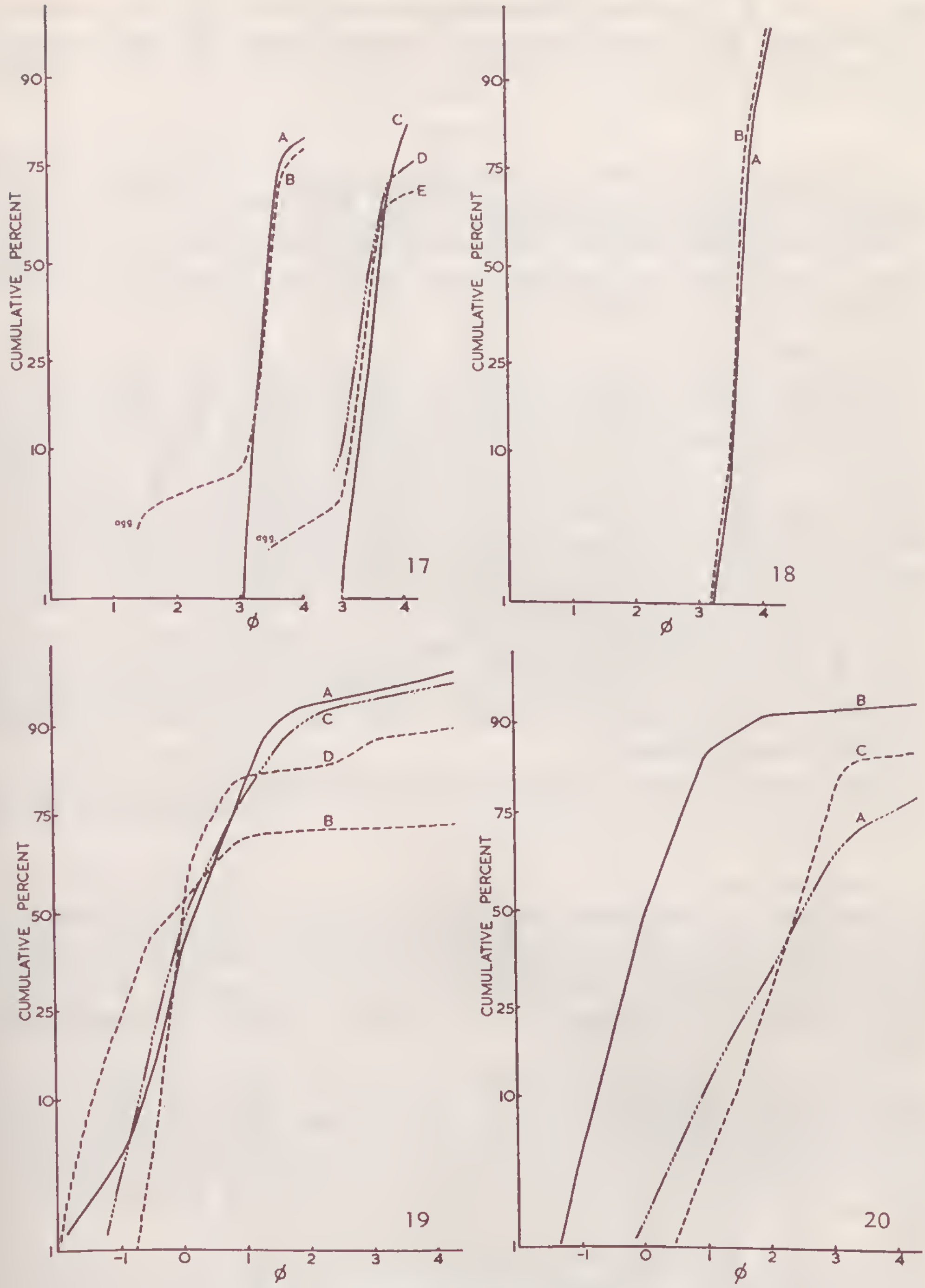


FIG. 17-20—Grain size distribution graphs.

Key:

FIG. 17—Graph A—bed 6(b); B—bed 7B(b); C—bed 10B(c); D—bed 9(f); E—bed 9(g).
FIG. 18—Graph A—bed 17(s); B—bed 19(e).
FIG. 19—Graph A—bed 7B(d); B—bed 10B(d), 7′ from base; C—bed 17(t); D—bed 20(f).
FIG. 20—Graph A—equivalent to bed 16 (d), 100 yds S. of Section 16; B—equivalent to bed 16(e), 100 yds S. of Section 16; C—bed 22(d), base of exposed part.

District occur in a restricted coastal exposure near Mt Martha. They consist of unfossiliferous, poorly sorted, grey clayey sands overlying the buckshot gravel horizon or other ferruginous sands. They are probably of fluviatile origin and have been recorded as beds 20(j), 21(i), and ? 22(d).

Structure

The structure of the Tertiary strata along the coast of the Mornington District has been previously mentioned in the description of the measured sections. Details regarding these and inland structures are presented here.

The principal structures are normal faults, and these may be accompanied by folding or warping of the strata due to drag on the fault plane, or to a varying displacement along the strike of the fault.

1. Manyung Fault

This extends from Frankston down to Locality 10, S. of Manyung Rocks. It has an average strike of 35°T (true bearing) and is downthrown to the NW. Its direction may be related to major joint systems in the granite and possibly in the Palaeozoic bedrock, seeing that it is parallel with the granitic contact at Mt Eliza (Fig. 4). At Locality 3, near Frankston, the lower Tertiary basalt can be seen faulted against the granite with a total displacement of probably less than 100 ft (Fig. 2) but, because of the southern dip on the downthrown side, the total displacement at Daveys Bay is thought to be much greater. The complete succession at this locality and the actual throw on the Manyung Fault will be known only when a bore is sunk in the vicinity of Davey Point.

At Dennant and Grices Creeks, the Balcombe Clay is downfaulted against the basalt. A similar relationship but with a complete sequence can be seen S. of Manyung Rocks, where severe drag on the downthrown beds has virtually created a monocline. The total throw in this area is about 300 ft, with both sides of the structure showing a backtilt.

Because the granite on the upthrown side is unconformably overlain by the Baxter Sandstones, movement along the Manyung Fault probably occurred during their deposition (i.e. in the late Miocene).

2. The Moorooduc Scarp

Inland from the Frankston-Manyung Rocks coastline, the land surface rises slowly to some 500 ft above sea level, then falls steeply to less than 200 ft along a scarp striking NE. from the Mt Eliza summit. Keble (1950, p. 54 and 62) described this physiographic feature as a 'contact ridge', which is 'a ridge surrounding the granitic intrusions due to the resistance to erosion of the metamorphic aureole'.

Mapping of the area has shown that the strike of the scarp makes a 30° angle to the strike of the granite contact (Fig. 4). Tertiary fluviatile sediments, several feet thick, are present near the top of the ridge (e.g. near Humphries Rd-Mountain Rd corner, Cranbourne, 1 mile, 165903), and occur as a widespread sheet covering the Palaeozoic bedrock on the gentle slopes to the north. On the S. side of the scarp the Palaeozoic rocks are covered with a thin layer of similar ferruginous sands.

These observations suggest that the scarp is of tectonic rather than residual origin. Faulting thus occurred at an angle to the granite contact during the Tertiary or Quaternary periods.

3. Structure at Mills Beach, Mornington

The nature and relationship of the Tertiary strata in the vicinity of Localities 12 and 13, near Mornington, suggest a tilt or downwarp to the south or west (see description of the geology). This structure is probably of late Tertiary age, prior to the period of ferruginization.

4. Fossil Beach Fault

Singleton (1941, p. 83) proposed a fault at the S. end of Fossil Beach in order to explain the relationship of various strata in the area. This structure is here referred to as the Fossil Beach Fault, and has a strike of about 30°T, with downthrow to the NW.

The cliff sequence and the information provided by the Fossil Beach bores show that normal faulting with a throw of some 70 ft occurred prior to the deposition of the Marina Cove Sand. If the fault movement occurred before or during the early stages of Balcombe Clay deposition, then a fault scarp of loose sand would have been exposed, insufficiently stable to avoid slumping and mixing. This has not occurred, and the beach exposure of the Balcombe Clay in the vicinity of the measured section (17) shows a steady dip of some 15° northward, possibly as a result of drag on the fault rather than due to the recent landslips.

Thus, it appears that faulting occurred during the final stages of deposition of the Balcombe Clay. In this case, the upthrown silt bed, e.g. 18 (g), is best considered as representing the base of the Balcombe Clay sequence. However, the restricted faunal evidence indicates that at least part of this unit belongs to the upper part of the Balcombe Clay (see text on Foraminifera). This means that most of the upthrown silt was removed and another layer of similar but younger sediment added. The prominent cementation of the lower part of this bed by 'jarosite' suggests that glauconite or pyrite was initially abundant, and this may have resulted from remnant minerals associated with the implied disconformity within the upthrown sequence.

Further elucidation of this structure awaits detailed study with close sample analyses, but it is clear that faulting occurred during the last stages of deposition of the Balcombe Clay.

5. Chechingurk Fault

The Chechingurk Fault, about ½ mile N. of Mt Martha, was first described by Keble (1950, p. 60) based mainly on physiographic evidence. It has a strike of about 110°T and is downthrown to the north. Thus, at the coast, the Baxter Sandstones are faulted against lower Tertiary basalt whereas, inland, the Palaeozoic basement is exposed on the S. upthrown side (Fig. 4). The throw on the fault is probably between 100 and 200 ft. Faulting occurred after the deposition of the Baxter Sandstones and prior to the period of ferruginization, in view of the ferruginous and level nature of the surface on both sides of the fault.

Inland from Mt Martha several faults have been described by Keble. These are the Balcombe, Tuerong, and Devilbend Faults, all of which strike in a NNE. direction (Keble 1950, Fig. 49). Their N. extension into the Mornington District is based on physiographic evidence (Keble ibid, p. 35). The scarcity of bores in this area does not enable any further definition of these structures.

Summary of the Stratigraphy and Sedimentation in the Mornington District

A generalized stratigraphic section along the coast from Frankston to Mt Martha is illustrated in Fig. 21. Because only a few measured sections show any degree of completeness, it has been necessary to utilize the information from adjacent sections. The base of the widespread Marina Cove Sand is used as a datum plane, seeing that tectonic activity has considerably displaced the strata since their deposition. Because of this, the diagram shows the nature, thickness, and relative horizontal distribution of the stratigraphic units, but does not portray the actual structure. A true representation of the coastal section in the south of the Mornington District and the Manyung Rocks area is given in Fig. 5 and 6.

Using the information provided by the stratigraphy and the physical nature of the strata, the Tertiary succession in the Mornington District may be summarized as follows, commencing at the base:

1. 'Sub-Basaltic Sediments'.

Poorly sorted sands and gravels, representing terrestrial sediments of early Tertiary age.

2. Older Volcanics.

Basalt flows and fragmental equivalents extruded probably during the Oligocene.

3. 'Post-Basaltic Terrestrial Sediments'.

Poorly sorted coarse and fine sands with some finer carbonaceous sediments, deposited in a terrestrial environment during Oligo-Miocene times.

4. Mt Martha Sand Beds.

Fine, well sorted quartz sands formed under littoral and nearshore conditions; best developed near Mt Martha. They are of probable Batesfordian (L. Miocene) age and mark the commencement of a marine trangression.

5. Harmon Rocks Sand Bed.

Poorly sorted coarse clayey sands occurring as a thin bed near Mt Martha. It represents a local return to fluviatile conditions during the Batesfordian.

6. Balcombe Clay.

Poorly sorted calcareous clayey silts with limestone concretions and an abundant

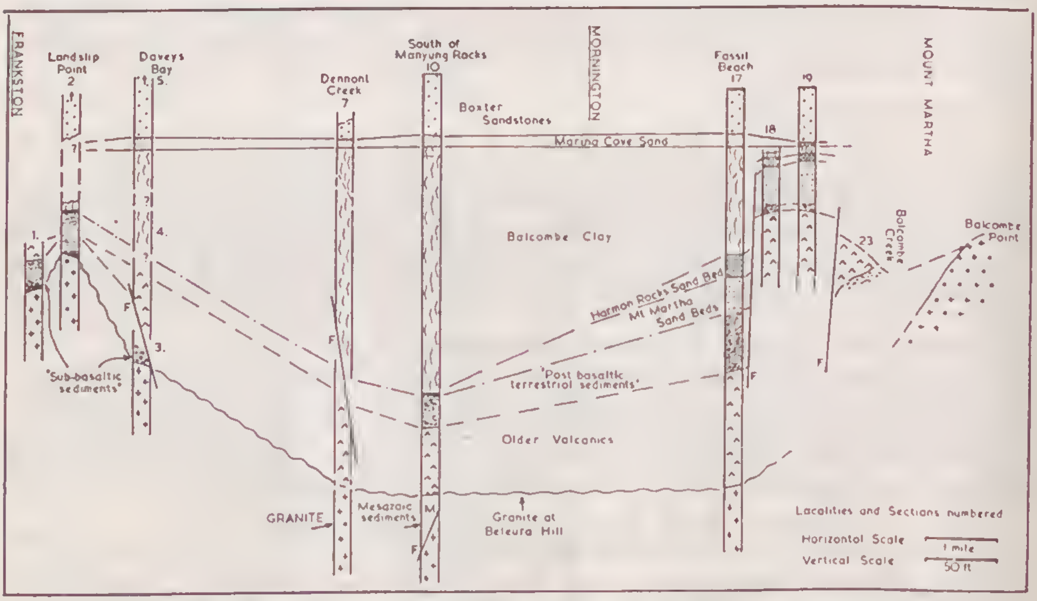


FIG. 21—Generalized stratigraphic section from Frankston to Mt Martha.